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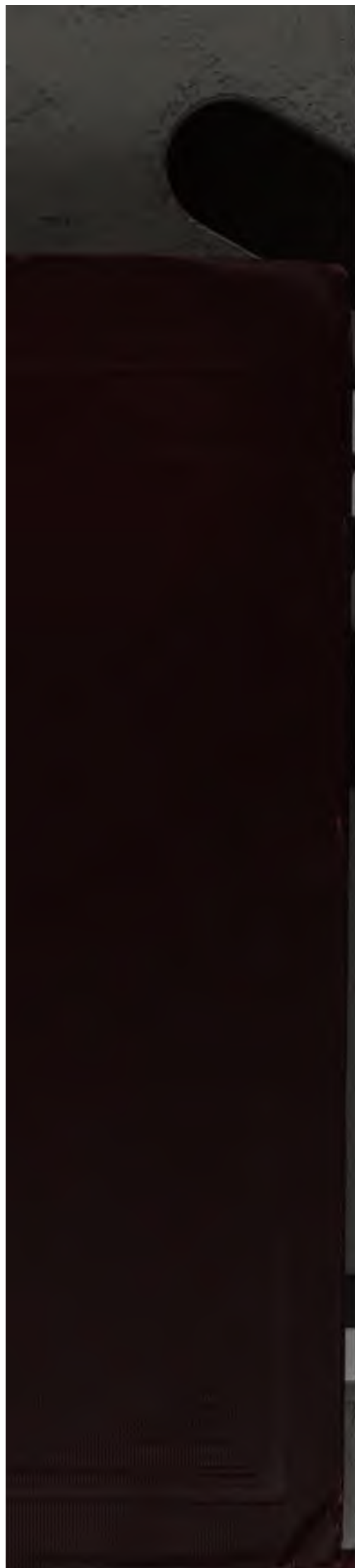
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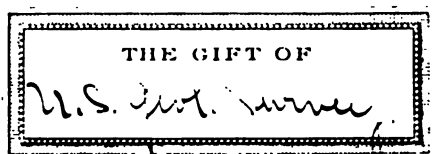
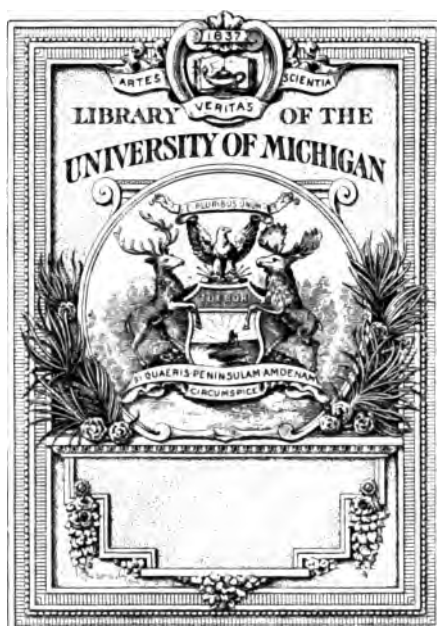
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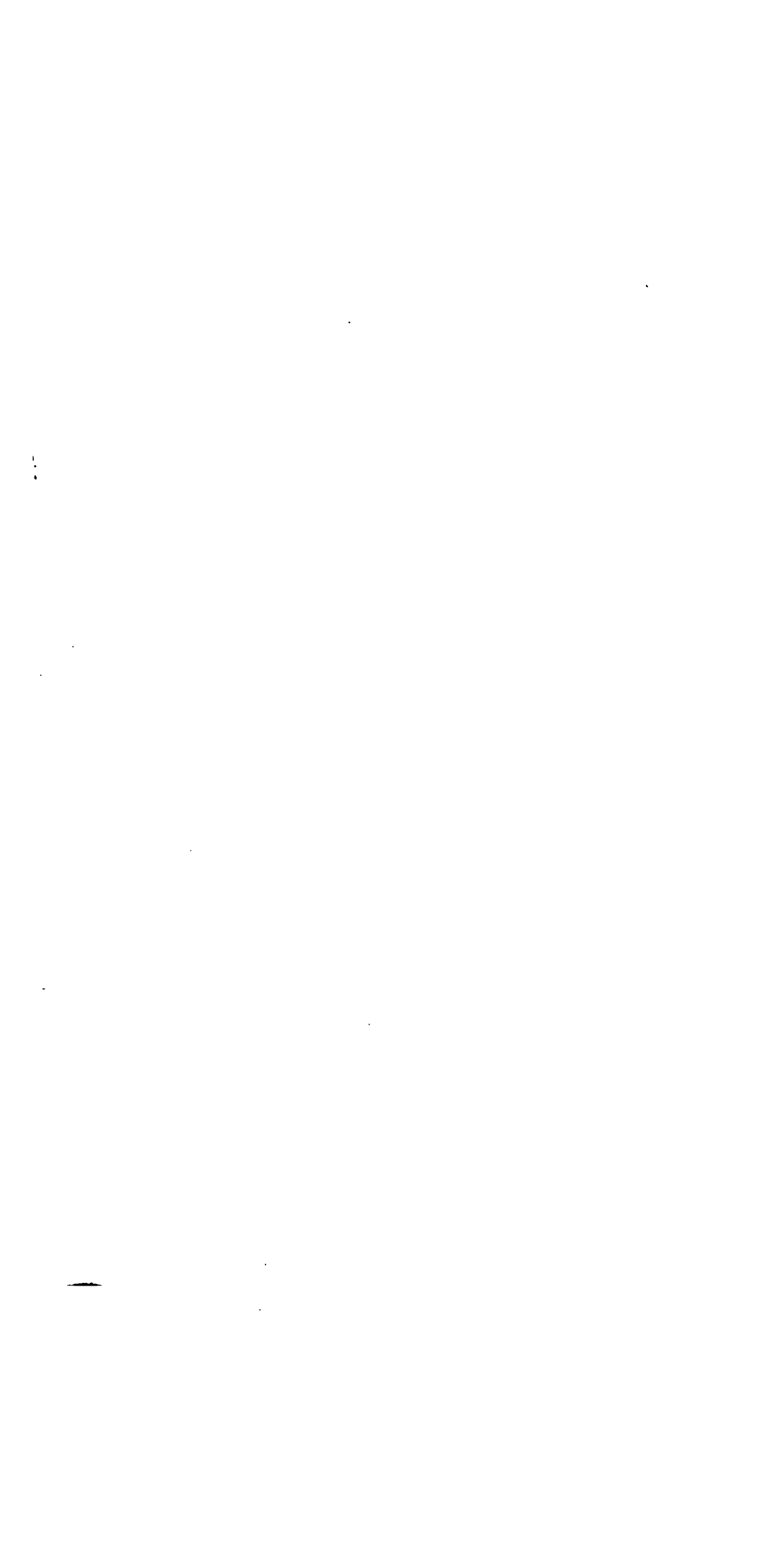




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STATE
GEOLOGICAL SURVEY
OF
NORTH DAKOTA

FIFTH BIENNIAL REPORT

A. G. LEONARD, PH. D., STATE GEOLOGIST



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ADMINISTRATIVE REPORT

ADMINISTRATIVE REPORT

University, N. D., Dec. 1, 1908.

To the President of the Board of Trustees of the University of North Dakota.

SIR: I beg to submit herewith my report on the work of the North Dakota Geological Survey during the years 1907 and 1908.

The publication of the Fourth Biennial Report of the Survey on the clays of the state was delayed somewhat on account of the large number of analyses and tests made on the clays. It was thought that the value of the results obtained would more than compensate for the delay that was necessary in order that they might be incorporated in the report. The volume is the largest yet gotten out by the Survey, containing 340 pages and a large number of illustrations and maps. Among the latter is a colored geological map of North Dakota, showing the distribution of the different rock formations and giving the location of the brick plants. On another map are located the high grade fire and pottery clays of the western part of the state, showing the outcrops and probable extent of the deposits. There has been a widespread demand for this report both from the clay men and others within the state, and also from geologists and other people in all parts of the country. Information regarding the valuable clay resources of North Dakota has thus been widely circulated and cannot fail to be of benefit to the state.

It is the wish of the Survey that its reports be employed as widely as possible in the schools in the teaching of Physical Geography and Elementary Geology. They are already coming into use in a number of the high schools where they are found helpful, especially in the study of local geography and geology. The many illustrations show the topographic features and rock formations, and the reports describe the natural resources of the region. During the past year many hundreds of the reports of the survey were distributed to the larger schools through the co-operation of the County

Superintendents. On his request the volumes were sent to the Superintendent and placed by him in those schools in which they would be of greatest service.

During the summer of 1907, the State Geologist had charge of a United States Geological Survey party of five, having associated with him Mr. Carl D. Smith of the Federal Survey. Detailed work was carried on in the region between Medora and Wibaux, Montana, the area which was covered by the survey being 24 miles wide and lying on either side of the Northern Pacific Railroad. Important discoveries were made regarding the number, extent and distribution of the coal beds, and much information gathered for a report on the region covered. This report is now being published in a bulletin of the United States Geological Survey, and the material which was secured will also be available for, and is being incorporated in, the forthcoming Fifth Biennial Report of the State Survey.

While we were camped near Medora, we were fortunate in having with us for over a week, Dr. A. C. Peale of the Smithsonian Institution, and Dr. F. H. Knowlton of the United States Geological Survey, who were spending the summer collecting fossils at many localities in North Dakota and other western states. These fossils which were collected will make it possible to determine the age of certain formations in the western part of the state, about which there has been some doubt.

Early in August a second party in the employ of the North Dakota Geological Survey, and consisting of the State Geologist and two students of the State University, J. W. Bliss and W. J. Smith, was organized for the purpose of extending the field work beyond the limits of the area covered by the Federal party. The latter party worked west into Montana, and in accordance with an agreement previously made with the United States Geological Survey, I was granted permission to turn the work over to another in order that the investigations might be continued within North Dakota, and additional material thus gathered for the State Survey Report. The party went south from Medora, following the Little Missouri river as far as the southern boundary of Billings county. The coal beds which outcrop in the bluffs bordering the valley and in the badlands on either side, were carefully traced, their thickness and extent noted, and their outcrops located on the map. On Little Beaver creek, in northwestern Bowman county a large collection of fos-

sil shells was made from the Pierre shale, and these were shipped to the University to add to its geological collections. Several weeks previous to this a choice lot of fossil leaves from near Medora had been sent in, along with some very finely preserved fossil fish from the top of Sentinel Butte.

From Little Beaver creek the party traveled northeast to Sand Creek Post Office and White Butte, where the interesting Oligocene formation found in that vicinity was studied and mapped. It was in these beds at the White Butte that the extinct three-toed horse and rhinoceros were discovered several years ago.

Some work was also done during the summer of 1907 in the northeastern part of the state by Mr. V. J. Melsted, who spent six weeks in a detailed study of the cement rock of the Pembina Mountain region. Careful search in the deep ravines and valleys of these mountains, often in the thick and tangled underbrush of that district, resulted in the discovery of many outcrops of the cement beds, which were located on the map. Samples from several localities were collected for analysis and considerable information gathered for a report on the cement materials of North Dakota. During the summer the State Geologist made a trip to the Pembina Mountains where several days were spent in going over some of the ground in company with Mr. Melsted.

During the field season of 1908 the North Dakota Geological Survey carried on work in the eastern and western portions of the state. In the western region the detailed investigations of the coal beds were continued and extended so far to cover those portions of Billings county not already visited or which had not yet been completed. The party, which consisted of the State Geologist, E. H. Wells and H. A. Hanson, traveled northwest from Dickinson, striking the Little Missouri river at the Short Ranch near the mouth of Ash creek, about 25 miles north of Medora. From this point the river was followed down to the mouth of Beaver creek, at the northern boundary of Billings county; then Beaver creek was followed up as far as the Montana line.

A large number of coal beds were found outcropping along the deep valley of the latter stream, and there was much evidence to show that this area is rich in coal. The party now went south through Sentinel Butte to Yule, spending several days in the vicinity of Bullion Butte on the way, and then on to the mouth of Bacon creek, near the town of Marmarth. After completing the

work in the southern part of the county we spent a week in the badlands lying east of the Little Missouri between the mouth of Sand creek and the Northern Pacific Railroad, and another week in the northeastern corner of Billings county.

The material gathered during the past summer, together with that previously secured during several years of field work in the southwestern corner of the state, will be used in the preparation of a detailed report on the geology and coal deposits of that section of North Dakota. This region was selected for detailed study because of the excellent opportunity afforded in the Little Missouri badlands for the examination of the coal beds, where these are so well exposed in numerous outcrops.

A very brief statement of some of the more important results of the field work during the season of 1908 may be given here. It was found that no less than 21 workable coal beds occur in Billings county alone, not all of them occurring at any one point, but some being found in one locality and some in another. These 21 coal beds range from four to thirty-five feet in thickness and are distributed through from 1,000 to 1,200 feet of strata. The aggregate thickness of the coal in these seams is $157\frac{1}{2}$ feet. Some of the individual coal beds cover large areas. One, with a thickness varying from 5 to 16 feet, has a known extent of 20 miles in one direction and 25 miles in another, with an area of at least 500 square miles, and probably much greater. Another seam of coal was traced 36 miles north and south, and 24 miles east and west, and while its known area as shown from outcrops is nearly 900 square miles, it undoubtedly has an extent of 1,000 to 1,500 square miles. This coal bed, with a thickness ranging from 9 to 15 feet and over, has been largely burned out or removed by erosion, but it still underlies a number of townships. At least half a dozen coal beds were discovered which were not before known to occur. The lowest coal seams in the geological column, and therefore the oldest, are those found in the vicinity of Yule, in southern Billings county. The highest and youngest are those which appear in Sentinel Butte and in the northern part of the county.

The discovery of the large fossil bones of the enormous land reptiles known as the dinosaurs was another important result of the summer's field work. These were found in the badlands, a few miles from the town of Marmarth, and several large boxes of them were shipped to the University to add to its collection. Many

of these huge bones were buried in the clays of the region, and some had been washed out and were lying on the surface. This discovery is of increased interest owing to the fact that these fossil bones will make it possible to determine the geological age of the strata in which the fossils occur, the age of the formation having been in doubt up to the present time.

The work in the eastern part of the state was in charge of the Assistant State Geologist, Mr. John C. Barry, a graduate of the Massachusetts Institute of Technology. It consisted in the mapping of the geological formations of Pembina, Cavalier and adjoining portions of Walsh and Ramsey counties, and the investigation of their natural resources. It was found that the northeastern part of North Dakota can be divided, on the basis of its topographic features, into three distinct districts, namely: the Red River Valley; the deeply dissected Pembina Mountains bordering the valley on the west, and the high rolling prairie which forms the greater part of Cavalier county.

The natural resources of the region consist of clay shales suitable for making excellent brick, cement rock, sand and gravel. The more extensive deposits of gravel and sand were located on the map wherever they were exposed at the surface, and in this way the localities where these occur were recorded. Much additional material regarding the cement rock was gathered, and together with that secured the year previous by Mr. V. J. Melsted, will be used as the basis for a report on the cement resources of North Dakota.

Early in September Mr. Barry made a trip to the gas field of Bottineau county for the purpose of investigating the gas wells of that region. Information was secured in regard to the depth, pressure, number and location of wells and other features of the district. The productive area at present appears to be confined largely to the vicinity of the Parker Farm, $9\frac{1}{2}$ miles south of Westhope. The depth below the surface of the gas-bearing sand varies from 160 to 240 feet and it doubtless lies near the base of the glacial drift. This sand layer has a thickness of about 20 feet. Prospecting is now going on with the hope of striking deep-seated and more extensive reservoirs of gas, and one well is down about 1,200 feet. The pressure is reported to be sufficient to blow off at least two million cubic feet per day. Experience in other states show that these comparatively shallow drift wells have not yielded a very

lasting supply, the reservoirs being of no very great extent. But further prospecting at greater depths is warranted by the possibility that deeper reservoirs may exist in the region. Gas is also reported about six miles northwest of Mohall, where several wells have been sunk.

In May of this year, I attended a conference of State Geologists, which convened in Washington, D. C. The gathering was held at the invitation of the Director of the United States Geological Survey, for the purpose of arranging plans of co-operation between the Federal and State Surveys, and to plan the season's work so that there should be as little duplication as possible. The North Dakota Geological Survey has been co-operating with the United States Geological Survey for several years and arrangements were made to continue this along several lines, as in the gathering of statistics of the production of coal, clay products, etc., and in the collection of well records, the Federal Survey bearing all the expense of this work. The conference afforded an opportunity for meeting and discussing with the government geologists various problems encountered in connection with the geology of this region, and was of distinct benefit to the work of the State Geological Survey.

In its work during the next few years the Geological Survey plans to continue the detailed investigations of the coal, clay and cement deposits of the state. These resources are increasing in value and importance with the rapid growth in population, and their proper development will be hastened and assisted by the information supplied by the State Geological Survey in its reports.

In this connection it is interesting to know that a recent estimate by one of the coal experts of the Federal Survey credits North Dakota with having more coal than any other state in the Union, and few people realize what this mineral wealth means to the state.

Another important line of investigation which the Geological Survey has taken up and will devote much attention to during the next few years is the problem of underground water. Well records from all over the state are being collected through the co-operation of well drillers and others, and these will furnish the data from which it will be possible to tell approximately at what depth artesian and other waters may be struck in any part of the region.

The subject of building stone is one which will receive attention and while stone suitable for building purposes is scarce in this

state, those localities where it does occur will be examined for the purpose of determining the extent and quality of the rock.

As in the past years, certain areas such as a county or several counties, will be selected for detailed study, the geology and economic resources will be investigated, the rock formations mapped, and the materials thus secured will be used in the preparation of reports on those districts.

A subject of the greatest practical importance to the people of the state is that of good roads and one of the problems connected with this is where to find the materials for the construction of such roads. It is known that in various localities over our state there are extensive deposits of gravel and sand which are suitable for road metal. As soon as the funds are available the State Geological Survey will undertake the investigation of these road materials, including the location and mapping of such deposits, but it cannot be done on the present small appropriation received for the work of the Survey.

It is also exceedingly desirable that the topographic mapping by the United States Geological Survey should be continued and pushed in this state in order that the excellent relief maps of the Federal Survey may include other areas in North Dakota. Many of the states, appreciating the great value of these maps, are appropriating large sums for this work and are thus co-operating with the United States Geological Survey. The latter organization does all the work of preparing the maps and publishes them; all that is asked of the state being that it shall bear half of the expense of the field work only. So far as it is able, the Federal Survey will put in a dollar for every dollar appropriated by the state. For two years the United States Geological Survey has done no topographic mapping in North Dakota, and if any more work of this kind is undertaken in this region the appropriation of the State Geological Survey will need to be largely increased, so that several thousand dollars can be set aside for this purpose. Whether the State Survey can undertake in the near future more than one or two of the lines of investigation outlined above will also depend on whether the present small appropriation is substantially increased.

The North Dakota Geological Survey is acquiring by exchange for its publications an excellent geological library made up of the reports of the Federal and various State Surveys, as well as the reports of a number of similar organizations in foreign countries.

The forthcoming Fifth Biennial Report of this Survey will contain the following papers:

"Mineral Production of North Dakota for 1907."

"Natural Gas in North Dakota."

"The Geology of Southwestern North Dakota With Special Reference to the Coal."

"The Geology of Northeastern North Dakota With Special Reference to the Cement Rock."

The report will also contain a chapter treating in a popular way the geology of North Dakota, intended particularly for the use of the schools.

Respectfully submitted,

A. G. LEONARD.

State Geologist.



The Little Missouri badlands in southern Billings county. This view and the one shown in Plate II were taken from the same point, looking in opposite directions. Photo by A. L. Fellows.



GEOLOGY OF SOUTHWESTERN
NORTH DAKOTA

WITH SPECIAL REFERENCE TO THE COAL

BY

A. G. LEONARD

THE GEOLOGY OF SOUTHWESTERN NORTH DAKOTA WITH SPECIAL REFERENCE TO THE COAL

BY A. G. LEONARD.

INTRODUCTION

The area treated of in this report occupies the extreme southwestern portion of North Dakota and includes the counties of Billings and Bowman. It is therefore bordered on the south by South Dakota, on the west by Montana, on the north by McKenzie county, while on its eastern border lie Dunn, Stark, Hettinger and Adams counties. The district has a length from north to south of 96 miles and a width varying from $38\frac{1}{2}$ to $53\frac{1}{2}$ miles, with a total area of about 4,567 square miles. Billings county alone comprises 3,400 square miles, being almost three times as large as Rhode Island, and Bowman county has an area of 1,167 square miles.

The region under discussion affords an exceptionally fine opportunity for the study of the coal beds, since there are abundant outcrops along the Little Missouri and its numerous tributaries, particularly in Billings county. The river traverses the area from south to north and has cut a deep valley along the sides of which the rock formations are excellently shown. Then, again, in no other portion of the state is there such a variety of geological formations and for this reason the district is of unusual interest. The famous and picturesque badlands of the Little Missouri, which do not extend far south of Billings county, occupy nearly one-third of the area, or some 1,400 square miles.

Until within the last few years the region has been given almost wholly to stock raising and has afforded a splendid range for vast numbers of cattle and horses, but recently the farmer has taken possession of much of the prairie land and is gradually crowding out and displacing the ranchman.

Geological investigations of a general character have been carried on in this region by a number of geologists. Among the first

to visit it was Charles A. White, who as early as the summer of 1882 examined the beds on top of Sentinel Butte and discovered in them two species of fossil fishes.¹ During September, 1883, Professor E. D. Cope spent some time collecting vertebrate fossils in what was probably southeastern Billings county, and he refers to the discovery of White River strata in that area.² In the summer of 1902, F. A. Wilder spent three weeks in the same county studying the coal beds,³ and the following season L. H. Wood went down the Little Missouri in a boat from Medora and continued the investigation of the coal deposits along that stream.⁴ In 1905 Earl Douglass of the Carnegie Museum at Pittsburg visited White Butte in southeastern Billings county and collected there many fossil mammals.⁵ The writer began work in the region in 1904, spending several weeks there during that year. In 1905 he had charge of a United State Geological Survey party which spent some time in southern Billings and Bowman counties, but not until 1907 were detailed investigations undertaken. In that year a United State Geological Survey party under the joint direction of A. G. Leonard and Carl D. Smith began work at Medora and carried it westward into Montana, covering an area 24 miles wide extending north and south of the Northern Pacific railroad. In the field work they were assisted by Fred H. Kay and W. H. Clark. The detailed study of the beds resulted in the collection of new data regarding the region which is briefly set forth in a recent bulletin of the United State Geological Survey.⁶ Again in 1908 the writer with a party spent several months in the field, extending the investigations to those portions of the area in which the work was not completed.

PHYSIOGRAPHY

DRAINAGE.

The drainage of the southwestern corner of the state is well developed and there is scarcely a township which is not traversed by several streams whose branches reach out to all parts of the surface. There are in this area nearly forty streams which have a greater length than ten or fifteen miles and the majority of them are much

¹Amer. Jour. Sci., Third Series, Vol. XXV, pp. 411-416.

²Proc. Amer. Philos. Soc., 1883, Vol. XXI, pp. 216-217.

³Second Biennial Rep. N. D. Geol. Surv., pp. 63-74.

⁴Third Biennial Rep. N. D. Geol. Surv., pp. 41-125.

⁵Annals of the Carnegie Museum, Vol. IV, Nos. III and IV, 1908, pp. 265-271.

⁶Bull. U. S. Geol. Survey No. 341, 1908, pp. 13-33.

longer than this. The Little Missouri river drains nearly two-thirds of the district and entering it near the extreme southwestern corner flows north across its entire length. Beaver creek, a tributary of the Little Missouri, and which joins the latter stream close to the northern boundary, includes in its drainage basin ten of the northwestern townships, while there is one township in the extreme northwest corner which drains into the Yellowstone river.

The rivers which flow east into the Missouri, the Knife, the Heart, the Cannon Ball and the North Fork of the Grand all have their sources in Billings and Bowman counties and drain a strip of territory along the eastern border.

The Little Missouri river, after traversing the southern half of the district, changes its direction and flows nearly due east for twelve miles; then again making an abrupt turn it flows northwest past Bullion Butte and continues in a northerly direction. South of Bullion Butte and near the point where the river changes its course from east to northwest, two large streams enter it from the south, namely, Deep and Sand creeks. The former has its source thirty miles distant in Bowman county, and the latter in White or Chalk Butte, and they empty into the Little Missouri less than a mile apart, their combined drainage basins comprising about 400 square miles.

Naming them in order from south to north, the following important creeks enter the river from the east, above the mouth of Deep creek: Coyote, Bacon, Indian, Cash and Spring creeks. From the west the tributaries are Big Box Elder, Little Beaver, Cannon Ball, Horse, Bull Run and Williams creeks.

Between the mouth of Sand creek and Medora, the large creeks entering the Little Missouri on the east are Third, Bear, Dance, Davis and Sully, while on the west they are Bullion, Garner and Andrews creeks, the last three named being the most important and varying in length from 20 to 25 miles. Andrews creek is followed by the Northern Pacific railroad between Medora and Sentinel Butte.

Between the railroad and the northern limits of the area the major tributaries from the east are Paddock, Government, Franks, Ash, Blacktail, Whitetail and Magpie creeks; from the west they are Knutson, Wannigan and Roosevelt creeks.

By means of these many large tributaries and numerous smaller ones the Little Missouri drains nearly two-thirds of the district.

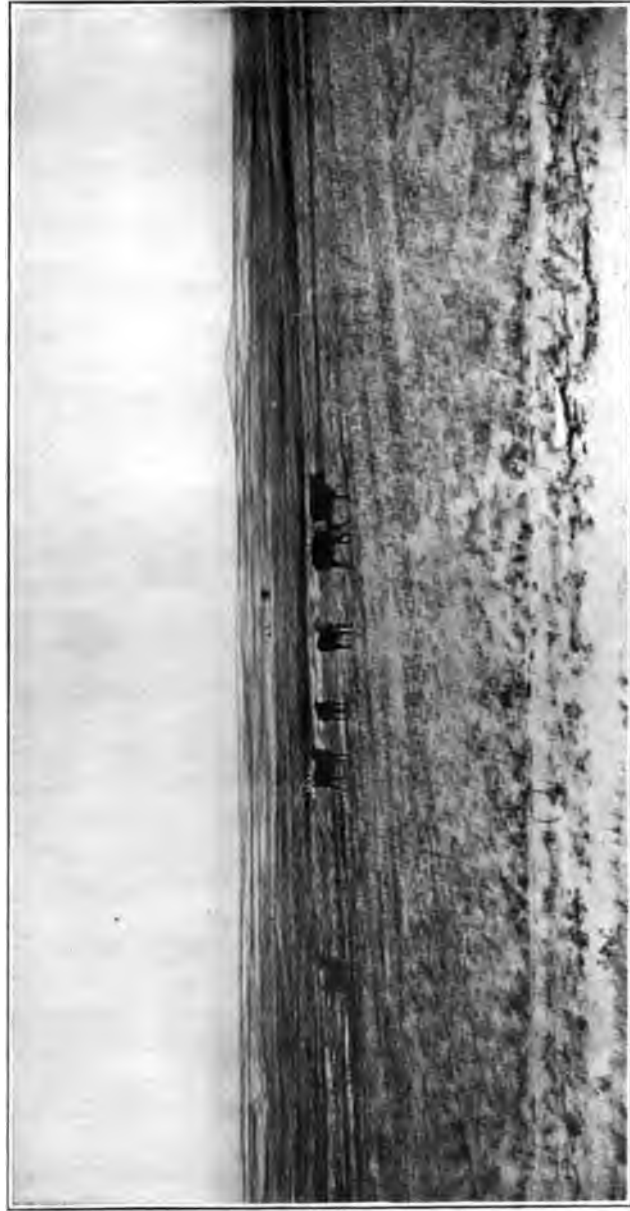
The North Fork of the Grand river flows for thirty miles near the southern border of Bowman county and with its three tributaries, Spring, Lightning and Buffalo creeks, drains over fifteen townships.

The North Fork and South Fork of the Cannon Ball river, which flows east into the Missouri, have a drainage area of over 440 square miles, their source being in the White or Chalk Butte, in southeastern Billings county. The headwaters of the Heart river also lie within the district under discussion, although they only drain a narrow strip of country along the eastern border. Farther north something over four townships drain into the Green river, a branch of the Heart, while in the extreme northeast corner the Knife river takes its rise.

The northwestern part of the area is crossed by Beaver creek, which enters from Montana and joins the Little Missouri close to the northern boundary. Elk creek is its chief tributary and together these two streams have a drainage basin within the district of about nine townships. The extreme northwestern corner, including some forty square miles, drains northwest into the Yellowstone river.

By far the greater number of streams in the area are intermittent and are dry during a considerable portion of the year, or their channels are occupied only by scattered pools of water. During and for several days following a rain the valleys are occupied by large creeks or, in case of a hard storm, by raging torrents. Then after the water has drained away the streams cease to flow and dry up wholly or in large part. Some of the larger creeks continue to flow throughout the year, as Beaver, Little Beaver, Sand and Deep creeks, while a few of the smaller, which are fed by good sized springs, as Ash creek, likewise have a constant flow.

The divide separating the drainage of the Missouri from that of the Little Missouri lies only 10 to 15 miles from the latter stream, but is from 100 to 120 miles west of Missouri river. It has an abrupt slope on the west and a gradual slope on the east. This is well shown at the head of Sully creek, eight or nine miles east of Medora, where a line of bluffs 200 feet high forms the western slope and on the opposite side the surface has a gentle inclination toward the east. The difference in the character of the country on the opposite sides of the divide is even more strikingly shown at the headwaters of Green river and Ash creek. The former stream has a broad, shallow valley, with a relatively slight fall; the surface is



The level, treeless plain. This picture and Plate I show the contrast between the upland plain and the badlands, and that they were taken from the same point indicates the abruptness of the change. Photo by A. L. Fellows.

rolling and occupied by farms. Ash creek, on the other hand, has a very narrow and steep-sided valley at its source, with deep and vertical-walled gullies in the bottom of it. The descent from the top of the divide is over 250 feet in a little over one mile and the creek has a steep gradient all the way to the river.

The streams on the west side of the divide, with their rapid fall and swift current, are eroding faster than those on the opposite slope and as a result the divide is being slowly shifted toward the east and away from the Little Missouri. The tributaries of the latter river are lengthening and reaching out into new territory, and are slowly encroaching on the headwaters of the Green river. The divide will continue to migrate eastward until the opposite slopes are more nearly equal and the rate of erosion is the same on both.

TOPOGRAPHY.

Four topographic types are represented in this region, namely, uplands, lowlands along the stream valleys, badlands, and river terraces. The upland areas comprise something more than one-half of the region and their surface is a more or less rolling plain. This is most extensive in the southern half of the district, although in the northern townships it occupies large tracts.

This upland plain or plateau is the result of long-continued erosion and doubtless represents a peneplain which has been produced since Oligocene time. Its elevation varies from 2,700 to nearly 3,200 feet above sea level. In this plain the streams and their countless tributaries have cut their channels and the region is very thoroughly drained. Everywhere the surface is made up of slopes leading to some drainage course. As one rides day after day over this treeless prairie, which stretches away in all directions as far as the eye can reach, its vastness and boundless extent make a lasting impression on the mind.

A conspicuous feature of this region is the high buttes which rise from 400 to 650 feet above the plain and form prominent landmarks which may be seen from afar. In Billings county there are at least eight buttes which are worthy of mention by reason of their size, namely, Sentinel, Camels Hump, Square or Flat Top, Bullion, Black, Chalk or White, East Rainy and West Rainy. With the exception of Camels Hump and White buttes, these are all flat topped and capped by a massive sandstone layer, which has given them their level summits. They are formed of nearly horizontal beds of sand

and clay which were once continuous over the entire region but have now been largely removed by erosion, leaving these remnants to show the former extent and thickness of the strata. The buttes are favorably located with reference to drainage and while the streams and rains have washed away hundreds of feet of material from this entire district, these outliers have been left, although they are themselves slowly wasting away under the ceaseless action of running water. The thickness of the beds thus removed from extensive areas in this part of the state can not have been much less than 1,000 feet, and it may have been more.

Sentinel Butte, which so far as known is the highest point in the state, has an elevation of 3,300 feet above sea level and rises 650 feet above the station of the same name, located on the plain below. On top of the butte are the remnants of a still higher formation which has been almost wholly removed, but which was doubtless several hundred feet thick. A number of the tributaries of the Little Missouri have their source close to the base of Sentinel Butte, and the latter is located on the divide between Beaver creek and the Little Missouri.

About five miles north of Sentinel Butte is Camels Hump, and Flat Top or Square Butte lies about the same distance to the east. Unlike most of the high buttes of the region Camels Hump has a rounded summit.

Bullion Butte, which is located within the great bend made by the Little Missouri, about fifteen miles south of Medora, is the largest butte in the region. It has an elevation of 950 feet above the river and from its summit all of the high buttes of the area can be clearly seen, together with others which are more distant. East Rainy and West Rainey Buttes are in the southeastern corner of Billings county, only a few miles from the border. Black Butte lies eight miles north of the southern boundary of the county and in it several tributaries of Sand and Deep creeks have their source. White Butte, so named from the chalky whiteness of the calcareous sands and clays forming it, is located five miles east of Black. It does not have the flat top common to all the other high buttes except Camels Hump, and it is not capped with the massive sandstone found on them.

These ledges of sandstone capping the high buttes and varying in thickness from fifty to a hundred feet, form vertical cliffs just be-

low their summits, and below these are the more gradual slopes produced by the weathering of the sandstone and shales. At the base of the sandstone cliffs are huge masses of rock which have broken off from the ledges above and accumulated in great talus piles. In northern Bowman county are the Twin Buttes, which form conspicuous landmarks visible from a great distance in every direction.

In addition to the larger buttes mentioned above there are great numbers of low buttes which are commonly capped with red burnt clay formed by the burning of lignite beds. This burnt clay or clinker has determined the height of these smaller buttes and protected them from erosion. They are well shown in the vicinity of Sentinel Butte, where they rise from 150 to 175 feet above the surrounding surface. Their uniform height is the result of the burning of the twenty-one-foot coal bed which is present in Sentinel Butte and the formation of the thick layer of clinker which occurs on the top of each.

The most prominent topographic feature of the entire region is the valley of the Little Missouri river, which, as already stated, traverses the entire area from south to north. The character of the valley varies so widely in different parts of its course that a description of one portion would not apply to another, and it will be necessary therefore to discuss separately the valley as it appears in Bowman and Billings counties. In the former county the bluffs rise only about eighty feet above the river. At this elevation there are broad flats which stretch away from the river and merge gradually into the upland plain. This plain back several miles from the stream reaches an elevation of 200 to 250 feet above the Little Missouri. Throughout its course in Bowman county the sides of the valley are covered with vegetation for the most part and the only outcrops are at points where the river swings against the bluff.

The valley as it appears in Billings county presents a strong contrast to the foregoing. The river has here cut its gorge to a depth below the upland plain of from 420 to 440 feet and with a width at the bottom of from one-half to one mile. The valley consists of an inner narrow portion and an outer wide portion. The inner valley is bordered by bluffs which rise very abruptly from the river to a height, in the vicinity of Medora, of 240 feet. At this elevation broad flats or terraces occur on either side of the Little Missouri. They have a width of from one to two or three miles and overlooking them are bluffs rising quite abruptly 160 to 200 feet above the

flats, or about 420 feet above the river. These wide flats were probably formed when the land was considerably lower than at present and the river, having reached base level, meandered back and forth over a flood plain several miles in width. The surface was then elevated, the river gained new erosive power and has since cut its inner gorge to a depth of some 240 feet below the old valley bottom, represented by the flats.

These wide flats are especially well developed at the following points along the Little Missouri, beginning at the south and going down the river. On the west side of the valley for several miles below Little Beaver creek, where the flat has an elevation of 110 feet above the river; in the vicinity of Yule, particularly on the west side of the valley and below the mouth of Williams creek, the elevation being 200 feet; within the large loop made by the river where it swings around to the east, just above the mouth of Spring creek, and on the north side of the valley throughout its eastward course, the elevation here being 210 feet; east of Bullion Butte, between it and the river, where the flat covers six to eight square miles and lies 230 feet above the river (Plate IV., Fig. 1); just north of here on the east side of the river, between Bear and Dance creeks, the flat having an elevation of 230 feet; just below Medora, and five miles below that town, between Knutson and Wannigan creeks, where the flats have an elevation of 240 feet; on the east side of the valley about two miles below mouth of Roosevelt creek, and several miles below this locality, across the river from Mikkelson Post Office, the high flats in this portion of the Little Missouri having an elevation of 280 feet above the river. (Plate III., Fig. 1.)

In some places there is not one, but two, three or even more of these high terraces, though generally there is one which is much more extensive and better developed than those above or below, and it is the elevation of this main flat that is given in the preceding paragraph, in case there was more than one at any given point.

The trench-like inner valley, which has been cut below the level of these broad terraces, has a nearly level bottom from which rise the almost vertical bluffs. These bare bluffs, with their horizontal banding produced by the alternating beds of variously colored sandstones and shales, rise with great abruptness from the flood plain of the river to a height of 200 to 300 feet and over. They do not merge gradually into the upper plain, but the same steep slopes continue clear to the top of the bluffs, so that they make a sharp angle



Fig. 1. The high flat or terrace bordering the valley of the Little Missouri near Mikkelson.



Fig. 2. The valley of the Little Missouri, showing the extensive low flat or terrace forming the valley bottom at the mouth of Blacktail creek.

with the upland surface. These nearly vertical walls line either side of the valley almost continuously except where they are broken by a tributary valley entering the main one.

Low terraces also border the river throughout its course, the upper one having an elevation of about twenty feet above the average stage of the water in the Little Missouri. In many places along the stream these terraces form extensive low flats which were once the flood plain of the Little Missouri, but are now high enough to escape overflow except in unusually high water. Among the largest of these lower flats are those occurring on either side of the river near the mouth of Blacktail and Whitetail creeks, the area occupied by these being not far from 1,200 acres. Other good sized flats are found at many points along the course of the valley. (Plate. III., Fig. 2.)

A very marked characteristic of the Little Missouri river is its meanders. It curves and winds back and forth across its valley, forming numerous great loops and causing its course through the county to be much longer than it would otherwise be. Measuring all the bends the length of the river in Billings and Bowman counties is approximately 175 miles, while if its channel were straight it would not be over 125 miles. In other words, the length of its valley is 125 miles, while the length of the crooked channel is 175 miles. Since the stream in its meanderings strikes first one and then the opposite bluff, it cuts the valley bottom into disconnected flats and the road following the valley crosses the river again and again, along several stretches it being necessary to ford the river twenty times in going as many miles. The meanders are particularly well developed in the vicinity of Yule and between that place and the southern boundary of Billings county, though they are by no means confined to this part of the valley. South of Bullion Butte, and on the south side of the river, in sections 3, 10 and 11 of T. 136, R. 103, there was formerly a large oxbow loop, but the river has cut across the narrow neck of land within the bend and taken the shorter course, abandoning its old channel, which is now largely filled with sediment.

The fall of the Little Missouri river between Medora and its junction with the Missouri is 520 feet, or an average fall of $3\frac{1}{2}$ feet per mile. Above Medora the fall is considerably greater, the stream descending 460 feet in the 70 miles between the Chicago, Milwaukee

& St. Paul railroad crossing at Marmarth, near the southern boundary of Billings county, and Medora, or an average fall of $6\frac{1}{2}$ feet per mile.

The Badlands.—Bordering the Little Missouri on either side and occupying almost one-third of the entire area, or approximately 1,400 square miles, are the famous badlands. They are not confined entirely to that stream, but are also found along Beaver creek, Deep creek, the Knife river and other streams. This tract of rough country along the Little Missouri has its greatest width near the northern border of the district under discussion, where Beaver, Blacktail, Whitetail and Magpie creeks with their many tributaries have eroded a labyrinth of deep gorges and ravines covering a strip twenty-five miles wide. South of here for a distance of forty miles, or as far as the mouth of Sand creek, the badlands are from fifteen to twenty miles in width. From this point to the southern boundary of Billings county they are not more than half as wide, while in Bowman county they are neither so well developed nor so extensive as farther north.

A word of explanation concerning the use of the term "badlands" may be added here. The land is not bad in the sense commonly understood by that word, for the soil is for the most part very productive when supplied with sufficient moisture. But the badlands are so extremely rough that they are very difficult to travel through and are in places impassible. They are bad in the sense probably meant by the old French term *mauvaises terre*, originally applied to the region with reference to its being a land bad for the traveler.

The badlands have been produced mainly by stream erosion and rain erosion acting on the soft clays and sands of the region. Through the agency of running water the nearly horizontal strata have been carved and sculptured into the infinite variety of weird and fantastic forms so characteristic of badland scenery. The erosion is greatly facilitated by the sparseness of the vegetation, the steeper slopes being almost bare of verdure. Though the region is one in which the rainfall is comparatively light, every shower is highly effective in washing away the unconsolidated clays and sands. Every slope, the sides of every butte and hill, bear the marks of the last shower. They are grooved with countless tiny channels formed by the rills and rivulets of water which poured down the slopes. Many creeks enter the river and each of them has its tributaries which are branching out and pushing back farther and farther. These

streams have cut their way deeply into the beds of clay and sand, thoroughly and minutely dissecting the region into a network of canyons, gorges, ravines and gullies. The badlands extend back from the river to the headwaters of the creeks tributary to it, and the latter are in most cases so near together that the rough country along one stream merges into that along the next stream, making a nearly continuous strip of badlands along either side of the Little Missouri.

In some places the change is abrupt from the upland plain to the badlands. There are commanding points on the edge of the latter where the view in opposite directions presents a most striking contrast. On the one side the eye looks out upon an indescribable waste, a chaos of bare ridges, bluffs, buttes, mesas, domes, pinnacles and countless strange forms carved from the soft strata of the region. (Plate I.) The scene has a strangeness and fascination so that one turns from it with reluctance and the eye never tires of returning to it. How different is the view presented in the opposite direction where a flat, featureless plain stretches away to the horizon, with not even a tree to break its monotony. The streams, if any are present, have cut only shallow valleys in the plain and the few slopes are gentle and grass covered. (Plate II.)

The greater part of the rain which falls upon the surface runs off at once into the streams, causing them to rise rapidly and become muddy torrents. Channels which have long been dry are filled by swiftly moving floods which sweep away vast quantities of sediment and rapidly erode the soft strata of the region.

One of the effects of these rivulets of water which flow during and shortly after a shower is the excavation of great gulches or trenches in the bottom of the valleys. These often have a depth of twenty to thirty feet, with vertical sides and flat bottom and they terminate abruptly at their upper end in an overhanging bank over which the torrent falls, rapidly undermining and cutting back the head of the gulch. These vertical-walled and deep gulches or miniature canyons sunk in the bottom of the valleys are very characteristic of the badlands and render travel through them so difficult.

One of the most notable features of the badlands is the bare clay slopes in which the variously tinted strata appear as horizontal bands running along the faces of the bluffs and buttes. The prevailing colors are shades of gray, yellow, brown, black and red. But while

many of the slopes are bare, the surface of the region as a whole is clothed with vegetation and furnishes excellent pasturage for stock.

While stream erosion and rain erosion acting on the horizontal beds of unconsolidated clay and sand are the chief factors in the formation of the badlands, the burning out of the beds of lignite has been of great importance in giving them their present aspect. The burning of the coal has been going on for thousands of years and is still in progress in many places. Coal beds from ten to fifteen feet thick and covering hundreds of square miles are now largely burned out and there are few extensive tracts in the badlands where the effects of the heat thus produced are absent. The overlying clays and sands are burned and changed to a red color and often they are completely fused to a slag-like mass. (Plate XI., Fig. 1.) This clinker, or "scoria" as it is locally called, is much harder and more resistant than the shales and sandstones of the region and often caps the buttes, ridges and bluffs, protecting them from erosion. The beds of clinker vary in thickness from a few feet to forty, fifty and even a hundred feet, and with their bright red colors are conspicuous features of badland scenery. In some localities, as in the vicinity of Flat Top and Sentinel buttes, huge masses of fused clay cover the slopes and form the capping layer of every butte. A thick bed of burnt clay forms the topmost layer of the higher bluffs and ridges along the Little Missouri from Medora to Bullion Butte, and the same clinker bed is found along Andrews creek and Sully creek, composing the masses seen from the railroad. The effects of the burning out of the lignite beds are well shown where the fires are still burning. The overlying clays settle down and form a depression nearly as deep as the thickness of the original bed of coal, at the same time wide cracks are opened in the earth and the materials above the coal are thus much broken and fractured. In this way a supply of air reaches the burning lignite and it smoulders slowly on, working its way back farther and farther as the surface settles and new fissures are opened over the burning bed. At the same time the clays are hardened and frequently fused, their color changing to red or pink. (Plate XI., Fig. 2.)

The effects of this destruction of the lignite beds are not confined to the badlands, and there are some extensive districts where the topography is very largely the result of this process. Thus, in the drainage area of Deep creek, west and southwest of Black Butte, the surface has a peculiar hummocky character when seen from the



Fig. 1. The Little Missouri valley at the mouth of Deep creek. In the background at the right the broad upper terrace between Bullion Butte and the river is well shown.



Fig. 2. Grass-covered slopes and scattered pines near the mouth of Sand creek, in the North Dakota Forest Reserve.

top of this butte, being thickly dotted with rounded knolls or hummocks. These are fifty to sixty feet and over in height and most of them are covered by and composed largely of masses of clinker. They have clearly been formed by the burning of a thick bed of coal, as a result of which the ground settled unevenly and much of the surface materials have been swept away by Deep creek and its tributaries, leaving the harder or more resistant portions behind to form the hundreds of rounded knobs with their covering of red burnt clay.

Elevations.—So far as known, the highest point in North Dakota is found in Billings county. The top of Sentinel Butte has an elevation of 3,350 feet above sea level, or 650 feet above the station of the same name. Bullion Butte, about eighteen miles southeast of Sentinel, rises 925 feet above the Little Missouri at the mouth of Bullion creek, or between 3,250 and 3,300 feet above sea level. But aside from these high buttes which rise hundreds of feet above the surrounding country, the surface of the upland plain itself, which occupies the greater part of the area, reaches a high elevation in certain districts. It probably attains its greatest height in north-western Bowman country, on the divide between Deep creek and Spring creek, the latter a tributary of the North Fork of the Grand river, and the Little Missouri. There is a large area here which is over 3,000 feet above sea level and the station of Rhame on the Chicago, Milwaukee & St. Paul railroad has an elevation of 3,189 feet.

Tracts of country occur on the west side of the Little Missouri, on the divide between that stream and Beaver creek in Montana, with elevations of 2,800 feet; and one or two miles west of Fryburg, on the edge of the badlands, the divide is 2,800 feet above sea level. Another high area is in northeastern Billings county, on the divide between the Green and Little Missouri rivers. The lowest point in the region under discussion is in the valley of the Little Missouri at the mouth of Beaver creek, the elevation here being approximately 2,070 feet above sea level. This gives a difference of elevation between the lowest and highest points of nearly 1,300 feet.

The bottom of the valley of the Little Missouri at Marmarth in southern Billings county, is 2,717 feet above sea level, or higher than the town of Sentinel Butte, located on the upland plain forty miles north.

STRATIGRAPHY.

The geological formations which occur in southwestern North Dakota belong to the upper Cretaceous and Tertiary periods of the earth's history. The Cretaceous rocks occupy a small area in western Bowman and southwestern Billings counties, while the Tertiary beds have a wide distribution and form the surface rocks over the entire region with the exception of the area just mentioned.

CRETACEOUS.

PIERRE SHALE.

The Pierre shale occupies an area five or six square miles in extent on Little Beaver creek, in northwestern Bowman county and extending across the line into Montana. The beds are brought to the surface by an anticlinal fold which appears to have affected a considerable area. The anticline so well shown on the Yellowstone, twelve miles above Glendive, if continued in the direction of the strike of the beds (S. 38 degrees E.), would include the Bowman county locality. Since ammonites and other marine fossils are reported to occur at several intervening points it is quite probable that the Pierre shale exposed on the Yellowstone and on Little Beaver creek is brought to the surface by the same uplift and the two areas of outcrop are perhaps continuous.

The Pierre shale, which is the lower member of the Montana group, is composed mostly of bluish gray shale, becoming dark and almost black when moist. The beds are jointed and weather into small flaky fragments. The rock commonly shows yellow spots or stains of iron oxide.

The top of the Pierre shale is well exposed on Little Beaver creek from two to four miles south of the Billings county line. In the southeast quarter of section 23, T. 132, R. 107, seventy-five feet of this jointed shale appear in a cut bank of the creek. These top-most beds of the Pierre contain numerous concretions of impure lime carbonate varying in size from several inches to six and eight feet in diameter. The calcareous concretions are very rich in fossils which are characteristic of the upper part of the Pierre. The following marine shells were collected from this locality and were identified by Dr. T. W. Stanton:

Pyrifusus.

Anisomyon subovatus M. & H.

Margarita nebrascensis M. & H.
Vanikora ambigua M. & H.
Nautilus dekeyi Morton.
Aporrhais biangulata M. & H.
Inoceramus cripsi var. *barabini* Morton.
Cuspidaria moreauensis M. & H.
Lucina occidentalis Morton.
Avicula linguiformis E. & S.
Callista deweyi M. & H.
Chlamys nebrascensis M. & H.
Leda (*Yoldia*) *evansi* M. & H.
Lucina occidentalis var. *ventricosa* M. & H.
Scaphites nodosus (Owen).
Dentalium gracile M. & H.
Anisomyon sp.
Pyrifusus newberryi M. & H.
Ostrea pellucida M. & H.
Nucula cancellata M. & H.
Protocardia subquadrata E. & S.
Lunatia sp.
Dentalium sp.
Anisomyon patelliformis M. & H.
Haminea occidentalis M. & H.
Fasciolaria (*Cryptorhytis*) *flexicostata* M. & H.
Baculites ovatus Say.
Cuspidaria ventricosa M. & H.?
Scaphites nodosus Owen var. *brevis* and *plenus*.

FOX HILLS FORMATION.

The upper member of the Montana group and the most recent of the marine Cretaceous strata is the Fox Hills formation, which overlies the Pierre and occupies a strip of country surrounding its outcrop, as shown on the map. The beds are somewhat lighter than those beneath, and when weathered are buff colored. They are well shown in outcrops on Little Beaver creek opposite the mouth of Corral creek and near the line between sections 7 and 18, T. 132, R. 106. At the base of the section exposed at this point, and not far above the base of the formation, there are about 25 feet of very finely laminated, sandy clay, composed of alternating light and dark laminae. These contain nodules of iron pyrites and there is an

absence of the jointing so well developed in the underlying Pierre shale. The fossil-bearing calcareous concretions are also wanting in these beds. Above the laminated clays occurs a ledge of yellow sandstone eight to ten feet thick and overlying the latter are fifty feet of light greenish gray sandstone. A section of these beds resting on the Pierre and exposed on Little Beaver creek is therefore as follows:

	Feet.
Sandstone, light greenish gray, massive	50
Sandstone ledge, yellow	8-10
Clay, sandy, finely laminated	20-25

At the top of this formation is an unconformity separating it from the overlying strata. The sandstone has here been eroded and its upper surface is undulating, while resting on it is a brown to black, very carbonaceous and clayey sandstone. This unconformity appears at two points along Little Beaver creek, one near the southern edge of section 7, T. 132. R. 106, and the other near the centre of the same section. (Plate V.)

No fossils were found in these beds lying between the Pierre shale and the unconformity and their reference to the Fox Hills formation is only provisional and is based partly on their stratigraphic position, which is similar to that of the Fox Hills sandstone in the Hell Creek region of eastern Montana, and partly on their resemblance to the beds of that region. They differ from the Pierre shale on which they rest in color, in consisting largely of sand, in their lamination, and absence of jointing. They are separated from the overlying strata by an unconformity. These beds thus appear to comprise a rather distinct division and for the reasons stated above they are provisionally referred to the Fox Hills formation.

TERTIARY.

LOWER FORT UNION OR DINOSAUR-BEARING BEDS.

For many years all the beds above the marine Cretaceous rocks were regarded as belonging to a formation which has been called by some the "Laramie," by others the "Fort Union." The work of the past few years in eastern Montana and western North Dakota has shown, however, that the Laramie probably does not occur at all in the region and that the beds above the marine Cretaceous belong to the Fort Union formation.



Fig. 1. The unconformity at the base of the Fort Union, on Little Beaver creek, Bowman county.

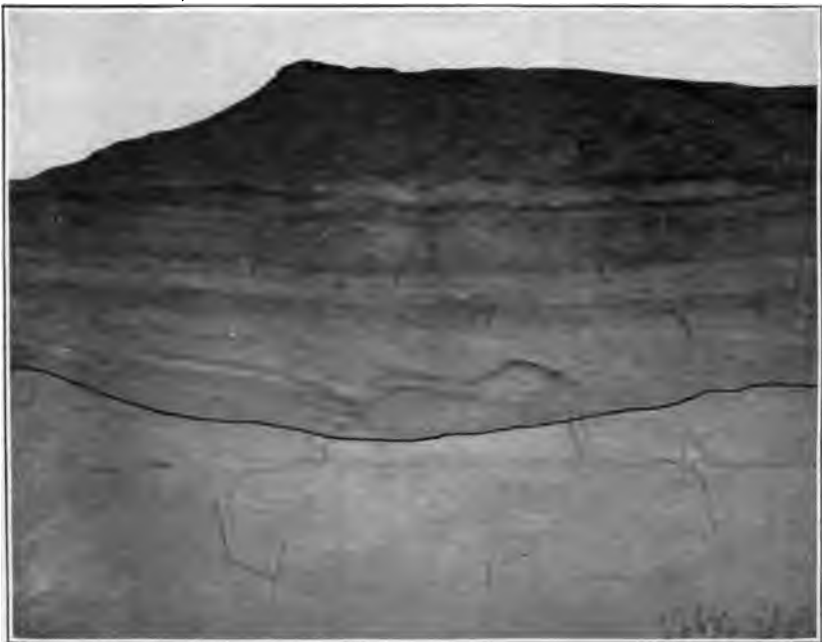


Fig. 2. The same unconformity as that shown in Fig. 1, as it appears at another point half a mile distant, also on Little Beaver creek.



Fig. 1. Bluff of the Little Missouri river at the mouth of Bacon creek, showing the dinosaur-bearing beds of the lower Fort Union.



Fig. 2. The Tepee Butte bluff of the Little Missouri, near the mouth of Deep creek, 584 feet high. The contact between the light colored middle member and the dark colored upper member of the Fort Union is well shown toward the top of the bluff.

The Fort Union rocks are readily separated into three members by a marked difference in character and appearance. The entire thickness of all three divisions is well shown in the area under discussion, which is especially favorable for the study of the various members of this formation. The upper beds are composed of rather dark gray sandstone and shale, with many brown, ferruginous, sandy nodules and concretions. The middle member is formed of light ash gray and buff shales and sandstones, which are remarkably uniform in color and appearance over extensive areas. These two divisions of the formation contain abundant plant remains of modern aspect which leave no doubt that the beds are of Fort Union (early Eocene) age.

The lower member is composed of the dinosaur-bearing somber beds. These likewise contain a flora which Dr. F. H. Knowlton, of the United States Geological Survey, regards as "beyond all question a Fort Union flora."¹ The basal portion of these somber beds contains large numbers of dinosaur bones and occupies the same relative position to the formations above and below as the "Hell Creek Beds" described by Mr. Barnum Brown.²

Associated with the dinosaur bones in the lower portion of the somber beds plants are also found which Dr. Knowlton states are likewise typical Fort Union species. The flora thus furnishes evidence that these dinosaur-bearing beds belong to the Fort Union and they are doubtless to be regarded as forming a part of that formation.

The somber beds cover a considerable area in southwestern Billings and western Bowman counties. They are well exposed in the bluffs of the Little Missouri valley for twenty miles above and below the point where the Chicago, Milwaukee & St. Paul railroad crosses that river. (Plate VI., Fig. 1.) Farther west in Montana these beds occur along the Yellowstone between Glendive and Miles City, and are well shown north of Miles City, in the Hell Creek region. In many places they are seen to be overlain by the light gray and buff middle member of the Fort Union. At Signal Butte near Miles City, for example, the somber beds rise 500 feet above the Yellowstone river, while resting on them and forming the upper part of the butte are 200 feet of buff beds belonging to the middle member. On the Little Missouri river below Yule the same contact between the lower and middle divisions of the Fort Union is seen.

¹In letter to the writer.

²Bull. Am. Mus. of Nat. Hist., Vol. XXIII, pp. 823-845, 1907.

The dinosaur-bearing beds as a whole have certain distinctive features by which they may be readily recognized. They are composed mainly of alternating layers of shale and soft sandstone, and have a notably dark and somber aspect in marked contrast to the buff and light gray of the overlying member of the Fort Union. The prevailing colors are dark gray, together with many brown bands, but weathered surfaces, especially when moist, frequently have a greenish gray or olive color. Beds of brown, carbonaceous clay shale are very common and conspicuous. These strata also contain much dark brown, ferruginous material, occurring both in thin seams and concretions, the latter being most numerous at certain horizons, and fragments of this cover the slopes in many places. Another characteristic is the great number of sandstone concretions, some small and others eight to ten feet in diameter, and very irregular in shape. (Plate VII., Fig. 1.)

No workable coal is found in the lower 300 feet or more of the somber beds, and in some portions of the area only thin coal seams occur throughout their entire thickness. Thus in the Pretty Butte section there is no coal bed over two feet thick, and in those which are present the coal is impure and mixed with clay. In the 250 feet of strata exposed at the mouth of Bacon creek there is practically no coal, the thickest seam being only fifteen inches, and the same is true for all the somber sandstones and shales exposed along the Little Missouri river from the Pretty Buttes south to the South Dakota line. But while only thin and unworkable coal beds occur in the lower part of this member, in the upper portion thick beds of coal are found in many places. In the vicinity of Yule five or six of these are present in the upper part of the formation, and the coal on Bacon and Coyote creeks is at about the same horizon.

At their base the somber beds are separated from the underlying formation by the unconformity already mentioned on a previous page. At the top they are not everywhere so sharply marked off from the overlying light colored member of the Fort Union, though they may generally be separated by means of their marked difference in lithologic character, including their contrast of color.

The thickness of the somber beds in southwestern North Dakota is approximately 600 feet. In the Hell Creek region of Montana the thickness of these strata, including the "Hell Creek Beds" of Mr. Barnum Brown, is 410 feet and they measure about the same at Glendive.

The character of this lower member of the Fort Union is shown in the following detailed section which was measured in the Pretty Buttes, five miles below Marmarth, on the west side of the Little Missouri river. It illustrates the rapid alternation of materials in this formation.

Pretty Buttes Section.

	Feet.	Inches.
Burnt clay bed, capping the buttes	26	
Clay, gray	2	
Sandstone, fine-grained, buff	8	9
Shale, gray	2	9
Shale, light buff	9	
Shale, chocolate brown, carbonaceous	2	
Coal, impure and dirty		11
Shale, brown		9
Coal, impure		8
Sandstone and shale, chocolate brown, carbonaceous...	2	
Sandstone, gray	12	
Shale, gray	2	
Shale, brown, carbonaceous	4	3
Coal, impure		8
Sandstone, fine-grained, gray	15	6
Shale, chocolate brown	1	7
Sandstone and shale, not well exposed.....	21	5
Shale, brown	1	
Sandstone, gray	11	3
Earth, black, carbonaceous		3
Sandstone, argillaceous, gray	3	7
Shale, gray	5	9
Sandstone, gray	3	9
Shale, gray	10	6
Coal, impure and dirty		11
Shale, chocolate brown	1	2
Sandstone		10
Shale, chocolate brown	1	3
Sandstone, argillaceous	3	7
Shale, brown, carbonaceous, with some coal.....	1	
Shale, gray	2	
Coal, impure		6
Sandstone, light gray	23	
Coal, impure, with 7-inch clay parting	2	
Shale, chocolate brown, carbonaceous	2	
Shale, sandy, changing in places to sandstone.....	58	
Coal and brown shale	1	4
Sandstone with some clay, gray	8	9
Shale, brown, carbonaceous	1	4

	Feet.	Inches.
Coal, impure	2	
Shale, brown, carbonaceous		8
Sandstone, gray, with some shale	63	4
Shale, brown, carbonaceous	1	
Shale, gray	1	6
Sandstone, gray	6	
Shale, brown, carbonaceous	2	3
Sandstone	3	
Shale, gray	7	5
Sandstone, gray, with limonitic concretions.....	16	6
Shale, gray	4	9
Shale, sandy, passing into sandstone above, gray; contains numerous brown, limonitic nodules.....	22	
Shale, dark brown, carbonaceous, with thin streaks of coal	1	1
Shale, light gray	6	10
Shale, dark gray to brown	2	9
Shale, gray, sandy above	5	2
Shale, brown, carbonaceous	3	4
Clay, greenish gray	2	6
Sandstone, gray, with great numbers of sandstone concretions and lenses	13	4
Shale, brown, carbonaceous	2	9
Clay, greenish gray	3	
Sand, gray	3	9
Shale, brown, carbonaceous, with streaks of coal.....	4	7
Shale, sandy	5	
Unexposed to river	20	

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All of the strata exposed in the above section belong to the somber beds, with the exception of the upper thirty or forty feet which are thought to belong to the middle member of the Fort Union.

The base of the section is probably nearly 200 feet above the base of the somber beds, since the contact of these with the underlying formation is found not far above river level seven miles south of here, on Little Beaver creek. The northward dip of the strata carries the contact below the river so that the lower portion of the somber member does not appear at the Pretty Buttes. These lower beds just above the contact are well shown, however, in the buttes and ridges back one or two miles from Little Beaver creek, where they are seen to be composed largely of sandstone. They have a very marked banded appearance, due to the alternation of dark brown and gray layers.

The dinosaur-bearing beds occur at the surface over a considerable area in southwestern Billings and western Bowman counties. They outcrop along the Little Missouri from the great bend six miles below Yule to the South Dakota line and extend back some miles on either side of the river, forming the surface formation of eighteen to twenty townships. In Billings county they extend east as far as the divide separating the headwaters of Bacon and Indian creeks from those of Deep creek.

This somber member constituting the lower Fort Union has so far yielded, according to Dr. F. H. Knowlton¹, some fifty species of plants and the list is constantly growing. As previously stated, this flora is beyond question a Fort Union flora. The following species were collected mostly in the upper portion of the somber beds, near Yule, Billings county, North Dakota:

Taxodium occidentale Newb.

Populus amblyrhyncha Ward.

Platanus Haydenii Newb.

Juglans rugosa ? Lesq.

Hicoria antiquora (Newb.) Kn.

Sapindus affinis Newb.

Viburnum Whymperi Heer.

Trapa microphylla Lesq. of Ward.

Cocculus Haydenianus Ward.

Near the mouth of Bacon creek, in the lower portion of the somber beds and associated with the dinosaur bones, a *Ficus* fruit was found. The same species is present in the Hell Creek beds and at Forsyth, Montana.

Five miles southwest of Yule, in section 16, T. 135, R. 105, a bed of fossil oyster shells was found, containing the single species *Ostrea subtrigonalis* E. & S.² Dr. Stanton considers the presence of these fossils here as sufficient evidence that the beds are not later than the Laramie. The shells were collected from about the same, or a slightly higher, horizon than the one containing the Fort Union plants, so that the testimony of the latter regarding the age of the somber beds is not in accord with that of the shells. The evidence of the plants as to the age of this member should probably have greater weight on account of the considerable number of species found in widely scattered localities.

¹In letter to the writer.

²Identified by Dr. T. W. Stanton.

The lower portion of the somber beds contains the remains of the great land reptiles known as dinosaurs, and the large bones of these animals were found in considerable numbers in the badlands at the mouth of Bacon creek. (Plate VII., Fig. 2.) The dinosaurs are an extinct group of reptiles whose members varied greatly in size, habits and appearance. Some were only three or four feet in height while others were of enormous size and were among the largest land animals which ever lived on the earth, being as much as sixty feet long. Some walked on all fours, but many had short front legs and used only their powerful hind legs for locomotion. Some were vegetable feeders, while others lived on animal food alone. One of the most common and remarkable of the dinosaurs was the clumsy and massive *Triceratops*, so called from its three horns. The animal had an enormous skull which projected backwards over the neck in a cape-like extension. It had a sharp, parrot-like beak, a stout horn on the nose, and a pair of large, pointed horns on the top of the head. It was this *Triceratops* whose remains were found in southern Billings county, along with the bones of other dinosaurs.¹

The somber beds of southwestern North Dakota have the same relative position and are doubtless to be correlated with the "Hell Creek Beds" of Mr. Barnum Brown, including the 100 feet of "Lignite Beds" overlying them, which he regards as probably Fort Union.² In the Hell Creek region of Montana they rest unconformably on the Fox Hills and are overlain by the typical, light gray and buff member of the Fort Union. The Hell Creek beds of that area contain the remains of many dinosaurs, among which *Triceratops* is the most abundant.

The somber beds also correspond in position with part of the "Dinosaur-bearing beds" of the Glendive region of Montana, described by the writer.³ In the section exposed at Iron Bluff, on the Yellowstone river a few miles above Glendive, 350 feet of dark shale and sandstone rest unconformably on a white, massive sandstone and these beds, which are barren of coal, contain Fort Union plants.⁴

¹Identified by Mr. C. W. Gilmore of the Smithsonian Institution, who says, "the larger specimen, on account of its large size, may be tentatively referred to the species *Triceratops horridus* (?)." A fragmentary scapula was identified as pertaining to the genus *Trachodon*.

²Bull. Am. Mus. Nat. Hist., Vol. XXIII, pp. 820-835, 1907.

³Bull. No. 316, U. S. Geol. Surv., Pt. II, pp. 198-200.

⁴Dr. F. H. Knowlton in letter to the writer.



Fig. 1. Near view of the dinosaur-bearing beds of the lower Fort Union, showing the numerous large concretions. Mouth of Bacon creek.



Fig. 2. Triceratops bones, showing one of the large horns of this dinosaur.

These strata at Iron Bluff resemble the somber beds of the Little Missouri river area of North Dakota, with which they are correlated, and near Glendive Mr. Barnum Brown found in them the remains of a *Triceratops*.

FORT UNION FORMATION.

The Fort Union, which is early Eocene in age, is the surface formation over the greater portion of the region under discussion, covering all of Billings and Bowman counties except a few small areas, as shown on the accompanying map. (Pate XVIII.) It is the Fort Union also that contains the coal beds of the district.

As was stated on a previous page the beds above the marine Cretaceous rocks were for many years thought to belong either to the Laramie or Fort Union formations. Recent work in North Dakota and Montana has shown that these beds are to be referred to the Fort Union and that the Laramie is wholly absent from the greater portion of the region. The name Fort Union was first used by Dr. F. V. Hayden in 1861 to designate the group of strata, containing lignite beds, in the country around Fort Union, at the mouth of the Yellowstone river, and extending north into Canada and south to old Fort Clark, on the Missouri river above Bismarck. The Fort Union formation is known to cover extensive areas in western North Dakota, eastern Montana and adjoining portions of Wyoming and South Dakota. The rocks are shales and rather fine-grained sandstones, with beds of lignite. They are fresh-water deposits and contain a flora of nearly 400 species of fossil plants, many of which resemble those of today. Numerous fresh water shells, and some reptiles also occur in the formation.

Mention has already been made of the fact that the Fort Union rocks are readily divided into three members, the lower of which has been discussed, under the title of the "dinosaur-bearing beds." It is the middle and upper members that are described here. The difference between them is very marked and has been observed over an extensive area. The middle or buff division outcrops in the bluffs of the Little Missouri river from Yule to the northern boundary of the area under discussion, while the beds of the upper member appear in the divides, ridges and high buttes, and are generally back a greater or less distance from the valley of that stream.

The middle portion is composed of light ash gray and buff shales and sandstones while the upper is formed of beds much darker in

color, mostly a dark and somber gray, with many brown, ferruginous, sandy nodules and concretions. The contact between these two members of the Fort Union is so clearly defined that it is readily distinguished even at a distance and is traced without difficulty wherever exposed to view. Over nearly one-half of Billings county a thick coal bed, or a layer of clinker formed by the burning of the coal, occurs just at the contact of the upper and middle series. But even where the coal or clinker is absent the line of separation is easily discernable. The workable beds of coal are more numerous in the middle member of the Fort Union, there being at least ten such beds in this portion of the formation, while the upper carries only half as many. Petrified wood, which is so abundant in many places in the region, appears to be much more common in the upper series, particularly where it occurs in the form of large stumps and trunks of trees, as in the vicinity of Sully Springs.

A comparison of the lower, somber beds with the other two members of the Fort Union shows that the latter were deposited under more uniform conditions and as a result the individual layers are more persistent and widespread.

The strata of the upper two divisions of the Fort Union formation may be seen along the Northern Pacific railroad between Fryburg and Medora. From the former station to the siding at Scoria the upper member is well shown in the badlands on either side, while between Scoria and Medora the middle member appears. The upper division is absent over practically all of southern Billings county, except in the highest buttes, and is probably not present in Bowman county.

No account of the Fort Union formation would be complete without mention of the vast quantity of burnt clay or clinker which forms so conspicuous a feature of this formation wherever it occurs. Beds of this clinker varying from 5 or 6 feet to 40 feet and over can be traced for mile after mile in the bluffs bordering the stream valleys, and in the ridges and divides, while many of the low buttes are capped with this material. The heat of the burning coal has been sufficient to burn, and in many places to completely fuse to slag-like masses, the overlying clay, turning it a red or salmon pink. The term "scoria" locally applied to this burnt clay is misleading, since it is very different from the scoria of volcanoes and is of course entirely different in origin. Further reference will be made to the clinker under the discussion of the coal beds.

The character of the Fort Union formation is well shown in the following detailed sections:

Short's Ranch Section.

This section is exposed in the steep bluff about one-fourth of a mile below the ford at Short's ranch, in the southeast quarter of section 1, T. 142, R. 102.

	Feet.	Inches.
Shale and sandstone, buff and gray, on which rest the somber beds of the upper series.....	17	
Coal	1	6
Sandstone, fine-grained, contains some clay, buff and gray	77	
Coal	1	
Shale, gray and yellow	16	
Coal, impure, and with two thin clay seams.....	1	
Shale and sandstone	17	
Shale, brown	1	
Shale, gray	7	6
Coal, and some brown clay		6
Shale, blue and yellow	7	
Shale, brown, carbonaceous		8
Sandstone with some clay	6	
Shale	4	
Coal		8
Clay, gray	1	6
Coal	1	
Shale, gray and yellow	3	
Sandstone, fine, gray	8	
Coal	2	6
Shale, blue	7	6
Coal	1	8
Shale, blue, plastic	5	6
Coal, with 6-inch clay parting 3 inches above bottom	2	6
Shale, blue, plastic	3	6
Coal		5
Shale, blue, plastic	3	
Coal		9
Shale, blue	3	
Sandstone, yellow and gray, fine-grained and laminated.	4	
Coal		1
Clay, gray		6
Coal, with 1 inch clay parting		9
Shale, bluish gray	4	
Shale, gray and brown, with a thin streak of coal.....		4
Sandstone, yellow and gray	3	
Shale, light gray, growing sandy above.....		16

	Feet.	Inches.
Shale, brown		4
Coal		18
Shale, light gray, with thin streak of coal		13
Sandstone, gray	3	
Shale, blue and yellow		8
Sandstone, yellow and gray	4	
Shale, sandy and finely laminated	1	4
Shale, blue		3
Coal		3
Clay		7
Coal		6
Sandstone, growing clayey above	2	
Shale, bluish gray, with thin streak of coal	6	
Sandstone, gray	5	
Coal	1	2
Shale, sandy, yellow	6	
Coal, with some brown clay		4
Shale, sandy and laminated toward top	14	
Coal		2
Shale, gray	3	6
Coal and brown clay		1
Sandstone, fine and gray	1	6
Shale, gray	2	
Shale, brown, with 2 to 4 inches of coal at base		8
Shale, light gray	2	8
Sandstone, gray, fine-grained, with hard ledge of rock near top; exposed above river	14	
	288	3

The beds appearing in the above section all belong to the middle member. It will be noted that although there are 17 coal seams none are of workable thickness, the thickest being only 30 inches. But the thick bed which outcrops less than two miles above and below the point where the section was made cannot here be far below river level.

The section which follows was measured three miles east of the previous one, in the northeast quarter of section 4, T. 142, R. 101., and lies wholly in the upper division of the Fort Union, its base resting on the lower member.

Section 3½ miles east of Short's Ranch.

	Feet.	Inches.
Sandstone and shale in alternating layers, more argil- laceous at the base		80
Coal band, thin		

	Feet.	Inches.
Shale, sandy	10	
Shale, bituminous	2	
Shale, sandy	10	
Powdery material, probably weathered, shaly coal.		
Shale, gray, forming where wet a sticky mud, sandy near middle	25	
Coal in two beds, the upper 1 foot, the lower 1-½ feet, separated by 4 inches of brown shale.....	2	10
Shale, gray, with hard, concretion-like masses of same color	55	
Coal	2	
Shale, sandy, gray	10	
Coal	1	
Shale, sandy, gray, more clayey above and below.....	50	
Coal	3	6
Sandstone and sandy, gray shale, rather coarse sandstone near center, fine-grained at top and bottom, with yellow bands	55	
Coal	1	
Sandstone, clayey, bluish gray, contains irregular ironstone bands, rather coarse sand at base, but grows gradually finer till at top it is a shale..	40	
Coal, impure	1	3
Shale, gray	7	
Coal, impure	3	
	358	7

The light colored beds of the middle member of the Fort Union are well exposed in the river bluff at Medora, where the following section occurs:

Medora Section

	Feet.	Inches.
Sandstone, clayey, gray and yellow, finer grained than rock below	10	
Sandstone, gray, soft, coarse-grained, massive, forms vertical escarpment near top of bluff	35	
Coal and carbonaceous shale	1-4	
Shale, gray and yellow	7	
Coal	3-4	
Shale	6	
Sandstone, clayey, fine-grained, gray	5	
Shale, yellow	1	6
Coal	6	
Shale, gray	1	
Shale, sandy, gray	5	
Shale, gray	1	6

	Feet.	Inches.
Shale, brown, carbonaceous, with thin coal seam	1	
Shale, gray	4	
Sandstone, clayey, gray and buff, fine-grained, laminated; in places forms hard ledge projecting beyond softer clays above and below	10	
Shale, with some sandy streaks, gray and yellow	5	
Shale, brown, with plant impressions	4	
Coal	1	6
Shale, gray and yellow, with sandy layers and a thin streak of coal	25	
Shale, sandy and passing toward the top into a hard, compact, fine-grained, gray sandstone, which forms a projecting ledge	3-4	
Shale, gray and yellow	5	6
Sandstone, fine-grained	2	
Shale, gray and yellow	4	6
Shale, sandy, gray fine-grained	5	
Coal streak, and brown, carbonaceous clay	1-2	
Sandstone and sandy clay, gray, in places the sand is cemented into hard rock, forming a projecting ledge	7	
Shale, gray	1	
Shale, brown	8	
Coal	1	
Shale, gray and yellow	20	
Shale, brown, carbonaceous	2	
Coal	4	
Shale, brown, with abundant plant remains, mostly stem impressions	1	
Shale, gray	3	
Sandstone, fine-grained and sandy shale	16	
Shale	4	
Shale, sandy	6	
Shale, gray	1	
Coal	2	
Shale	2	
Coal	8	
Shale	3-5	
Coal	11	
Shale and sandstone, not well exposed, to river	40	
	—	—
	251	6

Large collections of Fort Union leaves were made from two horizons represented in the above section, namely, 15 feet above the 8-foot coal bed and 6 feet above the 4-foot coal bed. The fossil plants occur in a compact, hard, calcareous clay which forms lenticular masses in the softer beds.

The beds of the upper member of the Fort Union occur in Sentinel Butte, where the following section appears:

Sentinel Butte Section.

	Feet.	Inches.
Clay, calcareous	10	
Limestone alternating with calcareous clay. The limestone is very compact and fine-grained, brittle, siliceous, and gray and white in color, weathering into very thin laminae. Contains fish remains	5	
Clay, very calcareous, gray weathering to greenish....	25	
Sandstone, gray, hard	80	
Shale, sandy, gray and yellow	30	
Shale, brown, with thin seam of coal	1	6
Shale, sandy, gray and yellow	53	
Coal		6
Sandstone, fine-grained, clayey	12	
Shale, brown and gray, containing many selenite crystals	4	
Sandstone, soft, fine-grained	1	
Coal	12-18	
Shale, brown and carbonaceous	1	
Shale, bluish gray	10	
Sandstone, gray	12	
Shale and sandstone, not well exposed	55	
Coal		2-6
Shale, sandy, gray	37	
Shale, gray, with no sand	2	
Coal	6	
Shale, sandy, brown at the top	5	
Sandstone, fine, gray	4	
Shale, sandy, gray, containing nodules	15	
Sandstone, finely laminated	4	
Shale, sandy, gray, with ferruginous bands	8	
Shale, sandy, brown	1	
Shale, gray	5	
Shale, gray, sandy, containing abundant siliceous and ferruginous nodules, arranged mostly in bands at certain horizons; these hard nodules project from surface of softer shale and cap small clay columns	25	
Sandstone and shale, not well exposed	25	
Coal	21	2
Unexposed to level of railroad at station of Sentinel Butte	190	
	650	2

The upper three members of the above section belong to the Oligocene formation. The 21-foot coal bed is about 50 feet above

the base of the upper division of the Fort Union. Dr. A. C. Peale and Dr. F. H. Knowlton collected leaves from five horizons in Sentinel Butte, all of these plants being characteristic of the Fort Union.

There is a bed of coal not far below the upper sandstone capping the butte, which does not appear in the above section, unless it is represented by the carbonaceous clay and coal seams 30 feet below the thick upper sandstone. A thick layer of red burnt clay formed by the burning of this coal shows at several points.

Tepee Butte Section.

One of the best exposures of the Fort Union beds anywhere in the region, and that showing the greatest vertical thickness of strata, occurs in the high, steep bluff of the Little Missouri, which is surmounted by the so-called Tepee Buttes. (Plate VI, Fig. 2.) It is one and a half miles north of the mouth of Deep creek, in the southwest quarter of section 5, T. 136, R. 102.

	Feet.	Inches.
Sandstone, with hard ledge at top, to top of Tepee Buttes	35	
Shale, sandy, buff colored	17	8
Coal	4	6
Shale, dark colored	10	
Shale, buff	4	6
Shale, dark colored	7	
Sandstone, brown, with many ferruginous concretions.	23	
Shale, buff, compact	31	9
Shale, chocolate brown		9
Coal	2	1
Shale, chocolate brown		5
Shale, dark colored	14	2
Shale, chocolate brown	1	
Coal	6	3
Shale, light gray	3	2
Sandstone	11	
Shale, dark colored	7	2
Coal		2
Shale, dark colored	2	2
Shale, chocolate brown	1	3
Coal		7
Shale, chocolate brown	1	
Bed R Coal	2	
Shale, chocolate brown		2
Coal	3	
Sandstone grading into shale	23	10
Shale, carbonaceous		5

	Feet. Inches.	
Shale, dark colored	9	8
Shale, sandy, buff	2	2
Shale, chocolate brown		11
Shale, sandy, buff	9	1
Shale, dark colored	2	3
Sandstone, fine, compact, brown	6	4
Coal		3
Shale	3	3
Shale, chocolate brown		4
Shale, buff	2	8
Shale, with streaks of coal	1	1
Sandstone, grading into shale	18	
Shale, and some coal	1	2
Sandstone, grading into shale	9	
Coal		6
Shale, chocolate brown		8
Coal		1
Shale, chocolate brown		2
Coal		1
Shale, carbonaceous		4
Shale, sandy, light gray	7	
Shale, chocolate brown		5
Shale, sandy	15	2
Coal		3
Shale		9
Coal		5
Shale, chocolate brown		6
Coal	1	7
Shale	1	2
Coal		3
Shale, sandy, grading into pure shale	16	
Shale	2	
Coal		6
Shale, buff	1	
Coal		2
Shale, sandy	8	5
Shale, chocolate brown		2
Coal	1	6
Shale, chocolate brown	1	
Sandstone, argillaceous, buff	13	7
Coal		8
Shale, chocolate brown		4
Shale, sandy, buff	5	6
Shale, black, carbonaceous		3
Sandstone	6	2
Shale, black carbonaceous		2
Shale, sandy	1	

	Feet. Inches.	
Shale, chocolate brown	9	
Shale, sandy, buff	3	3
Shale, brown	1	
Sandstone, argillaceous, buff	7	
Sandstone, grading into shale, gray	12	
Shale, buff	7	1
Sandstone, buff	2	
Sandstone, argillaceous, buff	2	
Shale, chocolate brown	10	
Shale, buff	2	6
Shale, black, carbonaceous	3	
Shale, chocolate brown	2	
Shale, buff	1	
Shale, brown, carbonaceous	1	6
Sandstone, gray	2	6
Shale, chocolate brown	2	8
Coal	2	2
Shale, chocolate brown	1	
Shale, buff, sandy	1	
Sandstone, fine-grained	3	3
Coal	2	2
Shale sandy, buff	2	
Sandstone, buff	4	7
Coal	1	4
Shale chocolate brown	3	
Coal	6	
Shale chocolate brown	6	
Coal	9	4
Shale, chocolate brown	2	
Shale, sandy, buff	5	
Sandstone, buff	26	
Coal	2	2
Shale, brown	2	
Coal	2	8
Shale	1	
Coal	8	
Shale, dark brown, carbonaceous	3	
Shale, sandy	2	6
Sandstone, grading above into clay, buff	17	6
Shale, chocolate brown	6	
Coal	10	
Shale, chocolate brown	6	
Coal	1	6
Shale, chocolate brown	2	
Coal	3	2
Shale	1	
Coal	1	8

	Feet.	Inches.
Shale, brown and buff	2	6
Shale, dark colored	11	8
Shale, blue	5	9
Sandstone, buff	49	6
Coal		4
Shale, sandy	11	
Sandstone, brown	4	
Shale, dark colored		10
Coal	1	8
Sandstone, buff, coarse	3	3
Sandstone, fine-grained, to river level	8	10
	—	—
	584	

The upper 183 feet of the above section, or all that portion above coal bed R, belongs to the upper member of the Fort Union.

These sections, taken from widely separated localities, show that this formation is composed of alternating beds of sandstone and shale with occasional beds of coal. The top of the Fort Union is formed of a rather hard sandstone 80 to 100 feet thick. This sandstone appears as the topmost layer in many of the high buttes of Billings county, as in Bullion, Sentinel, Flat Top and Black buttes. (Plate VIII, Fig. 1.) It forms vertical cliffs about their summits and huge blocks and masses breaking off from time to time accumulate at the base of the cliffs in great talus heaps. On Sentinel Butte and in White Butte the Oligocene beds are seen resting directly on this uppermost sandstone of the Fort Union. The base of the middle member appears along the Little Missouri river in the vicinity of Yule and for four or five miles below. The light colored beds forming the middle portion of the Fort Union are here seen resting on the dark, somber beds of the lower member.

Thickness of the Fort Union formation. The thickness of the upper two members is not far from 1000 feet. In Sentinel and Bullion buttes, where the entire thickness of the upper division occurs, it measures about 500 feet, and the thickness of the middle portion is approximately the same. In the Tepee Butte section 400 feet of the middle beds are exposed above the river, and the base of the section is believed to be not far from 100 feet above the bottom of the light gray and buff beds. Including the dinosaur-bearing beds the total thickness of the Fort Union is about 1600 feet.

As previously stated, the Fort Union contains a flora of nearly 400 species and a fauna comprising shells and reptiles. The fossil

plants collected in the area under discussion were found mostly in the middle member of the formation and came from widely scattered localities. The following are a few of the species occurring in the Fort Union beds:¹

Elk creek, near the Stone ranch.

Equisetum sp.

Mouth of Deep creek.

Viburnum Newberrianum Ward.

Viburnum asperum Newb.

Cedar canyon, two miles southwest of Medora.

Sequoia Nordenskioldi Heer.

Populus cuneata Newb.

Ulmus planeroides Ward.

Populus Richardsoni Heer.

Populus amblyrhyncha Ward.

Sapindus grandifoliolus Ward.

Viburnum antiquum (Newb.) Hol.

Populus daphnogenoides Ward.

Populus glandulifera Heer.

Planera microphylla Newb.

Carpites n. sp.

Taxodium occidentale Newb.

Diospyros brachysepala Al. Br.

Divide between Magpie creek and Knife river.

Taxodium occidentale Newb.

Pterispermites Whitei? Ward.

T. D. ranch, at mouth of Beaver creek.

Viburnum Newberrianum Ward.

One mile above Mikkelson.

Diospyros—may be *D. ficoides* Lesq. or new.

Near mouth of Bear creek.

Populus cuneata Newb.

One mile south of McKenzie county line in bluffs of Little Missouri.

Platanus nobilis Newb.

Viburnum antiquum (Newb.) Hol.

Viburnum Whymperi? Heer.

Corylus rostrata? Ait.

Custer Trail ranch, near Medora.

Asplenium tenerum.

¹Identified by Dr. F. H. Knowlton.

Near the base of Black Butte, and probably in the upper member of the formation, Mr. Earl Douglass collected the following plants, which were identified by Dr. F. H. Knowlton: *Asplenium* (a fern), *Equisetum* (horse-tail), *Populus* (poplar), *Thuja* (arborvitae), *Celastrus* (bitter sweet) and others.

Thirteen species of fresh water shells have been collected in the Fort Union beds of Billings county, and these were identified by Dr. T. W. Stanton. They comprise the following:

Near mouth of Bear creek in section 4, T. 137, R. 102.

Corbula mactriiformis M. & H.

Unio priscus M. & H.

Near the Moore ranch on Beaver creek, section 32, T. 144, R. 103.

Campeloma producta White.

Viviparus retusus M. & H.

Viviparus leai M. & H.

Thaumastus limnaeiformis M. & H.

About 3 miles below Mikkelson.

Campeloma multilineata M. & H.

Near the mouth of Beaver creek.

Corbula mactriiformis M. & H.

Viviparus trochiformis M. & H.

Viviparus leai M. & H.

Viviparus retusus M. & H.

Thaumastus limnaeiformis M. & H.

Near old Weidman ranch on Beaver creek, section 15, T. 144, R. 103.

Campeloma multilineata M. & H.

Campeloma producta White.

Viviparus leai M. & H.

Viviparus trochiformis M. & H.

Young ranch on Little Missouri river, section 22, T. 143, R. 102, 20 feet above upper coal bed.

Campeloma multilineata M. & H.

Roosevelt's old Elkhorn ranch, section 33, T. 144, R. 102.

Sphaerium formosum M. & H.

Bulinus longiusculus M. & H.

Micropyrgus minutulus M. & H.

Viviparus trochiformis M. & H.

Viviparus retusus M. & H.

Hydrobia sp.

Section 9, T. 144, R. 102, northern Billings county.

Unio sp.

Campeloma? sp.

The remains of vertebrates are rare except in the lower Fort Union. Several years ago a few bones were discovered in this formation by Mr. Charles Foley on the divide north of Andrews creek, in the southwest quarter of section 8, T. 140, R. 103. In company with Mr. Foley this locality was visited by A. C. Peale, F. H. Knowlton and the writer, and fragments of bones were collected in a black shale 30 feet above the base of the upper member of Fort Union. These were identified by Mr. J. W. Gidley as the bones of fishes, turtles, and the aquatic reptile *Champsosaurus laramiensis*. What is probably the same species was found by Mr. Barnum Brown in the Hell Creek beds of Montana associated with dinosaurs, and also in the overlying strata which correspond to the upper portion of the somber beds, or lower Fort Union of this report.

WHITE RIVER FORMATION.

The beds of this formation, which belong to the Oligocene, are confined to two small areas, one in southern Billings county in the vicinity of Sandcreek Post Office, the other on Sentinel Butte. In the latter locality they rest directly and conformably upon the thick sandstone which forms the top of the Fort Union. The beds occur only on the northern end of Sentinel Butte and their maximum thickness is not over 40 feet. (Plate VIII, Fig. 1.) They are clearly the remnants left by the erosion of a thicker and more extended formation which doubtless once covered a large area in this region. Where the strata are exposed in a low mound near the northwestern edge of the butte they are seen to be composed of light gray calcareous clay or marl, which contains, toward the top, beds of a nearly white, compact limestone. This limestone breaks readily into thin layers one-eighth to one-quarter of an inch thick, and some of the thicker layers become siliceous toward the center.

In one of the upper beds of this limestone are found the remains of two species of fresh water fishes. These fossil fishes were first discovered on Sentinel Butte by Dr. C. A. White, who visited the locality in 1882, and published an account of the deposit containing them.¹ They were described by E. D. Cope as belonging to a new genus and were named by him *Plioplarchus Whitei* Cope and *Plioplarchus sexspinosus* Cope.

¹Amer. Jour. Sci., June, 1883, Third Series, Vol. XXV, pp. 411-416.



Fig. 1. The flat summit of Sentinel Butte, showing cliffs of Fort Union sandstone and mound of Oligocene beds resting on the sandstone.



Fig. 2. Contact of the Fort Union and White River formations in White Butte. The thick sandstone ledge near the middle of the slope is at the top of the Fort Union.



Fig. 1. White Butte, composed of Oligocene (White River) beds, southern Billings county.



Fig. 2. White River beds exposed in White Butte, southern Billings county.

Since the fishes were not closely related to any previously described they did not serve to indicate the age of the beds in which they were found, but upon stratigraphic grounds Dr. White referred the strata to the Green River group of the Eocene, though he was by no means confident that this was their true position. In the light of more recent discoveries it seems much more probable that these beds on Sentinel Butte belong to the White River division of the Oligocene. It is now known that less than forty miles to the southeast are other deposits which rest directly on the upper sandstone of the Fort Union and which are known from their fossils to belong to the White River group. On the other hand, no beds of the Green River group are found any nearer than southwestern Wyoming and it is not at all likely that they ever extended this far north and east, while the White River beds cover considerable areas in South Dakota and Montana.

It is strange that these beds are entirely absent from the other high buttes of this region, although they are capped with the upper sandstone of the Fort Union and search was made for them on Bullion, Flat Top and Black buttes. The extensive erosion to which this region has been subjected during many ages and which is known to have removed at least from 800 to 1,000 feet of strata over a large area, has left only a few remnants of the White River deposits.

In the vicinity of Sandcreek Post Office, in southern Billings county, the beds of this group cover an area from eight to ten square miles in extent which occupies the highest part of the divide between the headwaters of the North Fork of the Cannon Ball river, and Deep and Sand creeks. They form the conspicuous, snow white elevations, known as White Butte or Chalk Butte. (Plate IX, Fig. 1.) Erosion has here left two narrow ridges about two miles apart, extending nearly north and south, the western three miles long and the eastern less than two miles in length, with a general elevation of 300 to 400 feet above the surrounding plain. Three miles to the west, on the opposite side of the valley of Sand creek, Black Butte rises 450 feet above the creek, being capped by the same sandstone as that forming the top of the other high buttes of the region. But the beds of the White River group are wanting on Black Butte, although occurring at a considerably lower level only three miles to the east. In White Butte they are, however, found resting directly on the thick upper sandstone of the Fort Union, which outcrops at

several points near the base of the western slope of the western ridge and also at its northern end. (Plate VIII., Fig. 2.) This sandstone here dips strongly to the east so that within a distance of three miles its dip carries it from the top of Black Butte to the base of the ridge on the opposite side of the valley, where it is over 200 feet lower.

The following is a general section of the White River beds as they occur in White Butte:

White Butte Section.

	Feet Inches	
11. Sandstone, rather fine-grained, light greenish gray in color, weathering into a greenish sand; to top of White Butte	105	
10. Clay, gray to light greenish color	20	25
9. Clay, hard and compact, calcareous, light gray, almost white; forms hard ledges which make low vertical cliffs towards the top of the butte, and weathers very irregularly	34	
8. Clay, dark gray, calcareous; the line of separation between this clay and No. 7 is sharp and distinct, the clay being considerably darker than the underlying sandstone	46	
7. Sandstone, light gray, rather coarse-grained	20	
6. Sandstone, very coarse-grained and pebbly; in places the pebbles are so abundant as to form a conglomerate. Shows cross-lamination. Pebbles composed of quartz, silicified wood, many varieties of igneous rock, among which porphyry is common, etc. Pebbles range in size up to 2 and 3 inches in diameter	26	
5. Clay, very light gray, slightly sandy	5	
4. Sandstone, light gray, very fine-grained and argillaceous	5	4
3. Clay, light gray to white, slightly darker than No. 2; contains some fine sand	10	6
2. Clay, very white and pure	6	6
1. Clay, white, containing some fine sand, hard and very tough when dry; rests directly on the sandstone of the Fort Union	14	4
	298	

In No. 8 of the above section was found the skull of an extinct species of ruminant, *Eoporeodon major* (?), which is found in the Oredon beds of the Oligocene.¹

¹Identified by Mr. J. W. Gidley.



Fig. 1. The coarse sandstone of the lower member of the White River beds in White Butte, showing effects of rain erosion.



Fig. 2. The pebbly sandstone of the lower member of the White River beds exposed in White Butte.

It will be seen from the section just given that the White River group is here composed of white clays at the bottom, on which rest a coarse sandstone which in places is filled with large pebbles; this is overlain by about 100 feet of calcareous clays which in turn are overlain by more than 100 feet of fine-grained, greenish sandstone. (Plate X, Figs. 1 and 2.)

These deposits represent all three divisions of the White River group, the lower or Titanotherium beds, the middle or Oreodon beds, and the upper or Protoceras beds. In the foregoing section Nos. 1 to 7 probably belong to the lower, Nos. 8 to 10 to the middle, and No. 11 to the upper division.

From the middle and upper horizons Mr. Earl Douglass in the summer of 1905, collected many fossil mammals.¹ Among these were the remains of many rhinoceroses, including very complete skulls, and several three toed horses. The remains of crocodiles were also found. The rhinoceroses belong to the species *Aceratherium tridactylum* Osborn and the horses to the two species *Mesohippus bairdi* (Leidy) and *Mesohippus brachystylus*? Osborn.

It was undoubtedly this same White Butte area which was discovered by Professor E. D. Cope in September, 1883. The discovery was announced in a letter written from Sully Springs, Dakota, and read before the American Philosophical Society.²

The following is a portion of this letter: "I have the pleasure to announce to you that I have within the last week discovered the locality of a new lake of the White River epoch, at a point in this Territory nearly 200 miles northwest of the nearest boundary of the deposit of this age hitherto known. The beds, which are unmistakably of the White River formation, consist of greenish sandstone and sand beds of a combined thickness of about 100 feet. These rest upon white calcareous clay, rocks, and marls of a total thickness of 100 feet. These probably also belong to the White River epoch, but contain no fossils. Below this deposit is a third bed of drab clay, which swells and cracks on exposure to weather, which rests on a thick bed of white and gray sand, more or less mixed with gravel. This bed, with the overlying clay, probably belongs to the Laramie period, as the beds lower in the series certainly do.

The deposit as observed does not extend over ten miles in north and south diameter. The east and west extent was not determined."

Then follows a list of 20 species of vertebrates which were col-

¹Annals of the Carnegie Museum, Vol. IV, Nos. III and IV, 1908, pp. 265-271.

²Proc. Amer. Philos. Soc., 1883, Vol. 21, pp. 216-217.

lected from this locality, including two species of fishes, tortoises (*Trionyx*), rhinoceroses and several *Oreodons*. The white calcareous clay below the upper sandstone is now known to carry fossils and the sand below this clay is also probably to be included with the White River group, as already indicated on a previous page. Professor Cope, in common with other geologists at that time, regarded the underlying beds as belonging to the Laramie, but as already stated, they are now on the basis of their plant remains known to be Fort Union in age.

Mr. Douglass in 1905 discovered another deposit of White River beds about 30 miles north and east of White Butte, in Stark county. The area, which is known as the "Little Bad Lands," lies some 12 to 16 miles southwest of Dickinson. All three divisions of the White River group are here present and a number of mammalian remains were collected. The nearest White River areas to the south are those mentioned by Professor J. E. Todd as occurring in northwestern South Dakota in the Cave Hills and Slim Buttes. The former locality is only about 35 miles from White Butte.

These Oligocene beds are believed to be in part lake deposits and in part river deposits. The lack of uniformity, the cross-bedding, and the coarseness of the materials of some portions of the formation seem to be the result of deposition through river action. Other portions were apparently laid down in the more quiet waters of a lake. It is not possible to determine at the present time whether the beds of the three North Dakota areas were deposited in one large lake covering a considerable tract in Billings and Stark counties, or whether they were accumulated in several small lakes. After their formation they were subjected to great and long continued erosion, which has removed all but these few small remnants of the Oligocene beds.

During the summer of 1905 Mr. Earl Douglass spent some time in the White Butte region making collections for the Carnegie Museum at Pittsburg. Through the kindness of Dr. W. J. Holland, Director of the Museum, and of Mr. Douglass, the writer was allowed to read the report in manuscript giving the results of the investigations, and wishes to express his great appreciation of the courtesy thus extended.

Mr. Douglas made a more detailed section of the White River beds than that given on a previous page, in which he includes lists of the mammalian remains discovered by him. This section is quoted

from his report, soon to be published by the Carnegie Museum. It is made from the eastern slope of the eastern portion of White Butte, and extends from one of the lowest exposures to the base of the upper division of the White River group.

Section of White River Beds at White Butte.

- Middle White River.
9. Gray sand, probably with a mixture of volcanic ash 6 ft.
 8. Clay or other fine material 3 ft.
 7. Cream colored fine sandy clay 1 ft.
 6. Nodular "Oreodon beds"—clay gray to light cream-colored on surface, darker cream-colored inside. Nodules brownish, cellular, sometimes containing bones, especially in lower portion. Beds sparingly fossiliferous from top to bottom. *Ictops*, *Ischyramys*, *Palaeolagus*, *Merycoidodon culbertsoni*, *Leptomeryx evansi*, *Mesohippus*, *Hyracodon*, *Aceratherium*, etc. 35 ft.
 5. A band of rock which weathers gray on the surface, becoming more nearly cream-colored toward the top, at the base of the Oreodon beds. Some thin layers are very compact. Bones black. *Merycoidodon*, etc. 15 ft.
 - 4c. A mixture of hard and soft rock (siliceous clay) weathering into tough, compact masses.
 - b. Tough rock with one seam containing nodules of barite.
 - a. Rock, white or gray at the bottom, with imperfect horizontal fractures or division planes. 25 to 30 ft.
 3. Yellowish sand with fine and coarse grains mixed with clay and having a slightly saline (?) taste. White on weathered surfaces. When the coloring matter and the fine clay are washed out it leaves a very clean sand, composed principally of clear quartz grains, which have been imperfectly rounded by the action of wind or water. 80 ft.
 2. Thinly and horizontally laminated clay and fine grit. The lighter laminae are light gray, the darker of a bluish tint. These laminae alternate irregularly on the weathered surface; they also unconformably overlie the brownish sand beneath. At the bottom of a trough-like depression there are two or three thin bands of iron-stained material about $\frac{1}{4}$ inch in thickness. In tracing this upward it was sometimes laminated and sometimes massive. Part of it is gray sandstone, and the structure makes it appear as if part of the mass had been deposited in an uneven surface of the other portion. Scattered

Lower White
River.

over the surface of the darker gray portion are fragments of petrified wood; rounded pebbles of white quartz; granite; granitic rock without mica; gray, bluish-gray, brown, and reddish quartzite of compact texture; and gray, brown, reddish, purplish, and bluish cellular pebbles, some of which look like volcanic material, but are mostly granular rock, some of the crystals of which have been dissolved. There fragments vary in size from that of fine sand to large pebbles, some of which are six inches in diameter. There are also flat, flinty fragments which contain impressions of plants... 35 ft.

1. Lowest exposure found at this place. A brownish-gray iron-stained, homogeneous sand with small, brown concretionary masses. Upper surface not level, but having depressions filled with No. 2. 5 ft.
- Total thickness of section, 210 ft.

Another section from another locality on White Butte partly supplements the one just given as it extends upward through the Upper White River beds. Its lowest member corresponds with No. 5 of the preceding section, beginning with the top of the Titanotherium beds and extending upward through the Oreodon and overlying beds as high as they are exposed at White Butte.

Section of upper portion of western ridge of White Butte.

Upper White
River.

13. Green sand, mostly unconsolidated, gray sand, shale, and fragments of bones 18 ft.
12. Green sand. Fragments of bones of Rhinoceros, etc. 8 ft.
11. Green sandstone, unequally hardened so that it contains irregular cavities (weathered pits) and root like rods 8 ft.
10. Green sand with some nodules, gray on surface near top 38 ft.
9. Gray shale, hard in places, sometimes greenish in color. Bones of Rhinoceros 24 ft.
8. "Rubbly" sandstone in rounded egg-shaped forms 4 ft.
7. Harder sandstone than No. 6 5 ft.
6. Fine greenish sand and clay, in one stratum cracking vertically. Some imperfect horizontal parting planes 12 ft.
5. Green sand with sandstone concretions..... 6 ft.
4. Green and gray clay shales 6 in.
3. Fine gray sand, with some clay. *Merycoidodons*, *Hyracodonts*, *Mesohippus*, etc. 12 ft.

	2. Pinkish-gray clay with brown cellular nodules. "Oreodon Beds" <i>Ictops</i> , <i>Gymnoptychus</i> , <i>Eumys</i> , <i>Ischyromys</i> , <i>Palaeolegus</i> , <i>Mesohippus</i> , <i>Hyracodon</i> , <i>Aceratherium</i> , <i>Merycoidodonts</i> , <i>Leptomeryx</i> , etc. 32 ft.
Middle White River.	1. Tough sandy clay with appearance of stratification, without brown nodules, but containing a few remains of <i>Merycoidodonts</i> . Probably belongs to "Oreodon" horizon 6 to 8 ft. Total thickness of section 163 ft. Total thickness of beds at White Butte about 320 ft

The Oreodon beds have nearly the same appearance wherever exposed but the overlying beds are more variable, and probably no two sections would be just alike. The Oreodon beds at White Butte are not rich in mammalian remains, and most of the fossils are fragmentary, though in one place three skulls with portions of skeletons of *Merycoidodon*, and a skull with part of a skeleton of *Ictops* were found. In No. 3 of the last section, portions of skulls of *Merycoidodonts* were obtained but probably of different species from that of the nodular beds. No. 5 contains many remains of *rhinoceroses*. Two good skulls were found which have been referred to *Aceratherium tridactylum*. Some fragments of bones and teeth of reptiles and mammals, including jaws of rodents and the tooth of a crocodile were found in No. 6. Fragments of bones were found in most of the higher horizons.

ALLUVIAL DEPOSITS.

The youngest of the formations occurring in southwestern North Dakota are the recent alluvial deposits of the stream valleys. They are of comparatively small extent, although along the Little Missouri river and some of the larger streams extensive flats or low terraces are covered with sediment laid down during times of flood. These deposits, composed of sand and sandy clay form the rich soils of the valley bottoms. The strip of alluvium along the Little Missouri varies in width from one-half to one mile and more. It is widest where large tributary valleys join the main one.

Billings and Bowman counties were not affected by the continental ice sheet which covered the greater portion of the state and left behind the drift deposits. No glacial materials are found in this region.

STRUCTURE.

The geological structure of the region under discussion is very simple, the beds being nearly horizontal over most of the area and having undergone little folding since their deposition. Reference has already been made on a previous page to the anticline which has brought the Pierre shale to the surface in northwestern Bowman county.

This anticlinal fold is probably a continuation of the one so well shown on the Yellowstone near Glendive, the axis of which has a trend S. 38 degrees E. As a result of this disturbance the strata over a large territory have been slightly tilted and given a gentle dip toward the north and east. As might be expected, this dip is not uniform over the entire region, but is greater in some places than others. Thus the average dip between Marmarth and Sentinel Butte is approximately 20 feet to the mile, while for several miles on Little Beaver creek the dip is 50 feet per mile, and in the vicinity of Yule there is also a dip to the northeast of 50 feet to the mile. At Marmarth the base of the somber beds is not far from 2,600 feet above sea level, and at Sentinel Butte the top of the middle series of the Fort Union lies 2,840 feet above sea level; in other words the same strata are nearly 850 feet lower at Sentinel Butte than at Marmarth. From Sentinel Butte to Medora there is a dip toward the east of 23 feet per mile, while from Bullion Butte to Medora the dip toward the north is 16 feet to the mile. North of Medora the dip of the beds is considerably less, being not over 3 to 5 feet to the mile on the average, and the strata are slightly undulating.

The unconformity between the Fox Hills formation and the somber beds has already been mentioned in connection with those formations. It is well shown at two points on Little Beaver creek, in section 7, T. 132, R. 106. Here the massive sandstone forming the top of the Fox Hills is seen to have undergone erosion before the deposition of the brown and black, highly carbonaceous and argillaceous sandstone, which shows cross-limitation in places. Some of the depressions of the former land surface have been eroded to a depth of 6 feet below the adjoining elevations.

THE COAL DEPOSITS.

CHARACTER AND EXTENT.

Almost the entire area under discussion is underlain by workable beds of coal. The only districts where no coal is found are eight or

ten townships in western Bowman county, and several townships in southwestern Billings county, where the barren somber beds occur at the surface. Outside these restricted areas it is probable that a hole put down in any portion of the region would strike one or more workable coal beds.

The Little Missouri badlands afford exceptionally favorable opportunities for the study of the coal deposits on account of the great number of outcrops, which make it possible to trace individual beds almost continuously over extensive tracts. It is thus possible to correlate and place in their relative positions in the vertical section coal beds which outcrop in widely separated portions of the field. The number of workable coal beds in southwestern North Dakota is now known to be at least 21, not all of them being present at any one point, but some occurring in one locality and some in another. They are distributed through from 1,000 to 1,300 feet of strata and range from 4 to 35 feet in thickness. The aggregate thickness of the coal in these 21 beds is 157½ feet.

It was formerly supposed that the lignite beds were not of great extent and covered but comparatively small areas, one seam thinning out and being replaced by others at a different horizon. But the detailed work of the past two years has shown that some of the individual coal beds cover large areas. One, with a thickness varying from 5 to 16 feet, has a known extent of twenty miles in one direction and twenty-five in another, with an area of at least 500 square miles, and probably much greater. Another bed of coal was traced 36 miles north and south and 24 miles east and west, and while its known area as shown from outcrops is nearly 900 square miles, it undoubtedly has an extent of 1,000 to 1,500 square miles. This coal bed, which had a thickness ranging from 9 to 15 feet and over, has been largely burned out or removed by erosion, but still underlies a number of townships. Other beds of coal are much less persistent and the area covered by them is comparatively small.

The coal beds vary in thickness from less than an inch to 35 feet. There are at least 6 which have a thickness of 10 or more feet and three which measure over 20 feet. The thickest is the 35-foot bed which outcrops on Sand creek; the Bacon creek bed is 30 feet and the Sentinel Butte bed is 21 feet thick. Beds of coal from 4 to 8 feet thick are common.

The coal of southwestern North Dakota, as of the rest of the state, is mostly a brown lignite with a decidedly woody structure, exhibiting clearly the grain of the wood and having the toughness of that material. It breaks or splits readily along the grain but is broken with difficulty in any other direction. Portions of flattened trunks and branches are often found in the beds, bearing a close resemblance to the original wood except for the brown color. The same bed is frequently more woody in some portions than others, being made up of alternating layers of tough brown lignite, and black, lustrous, brittle material.

In one outcrop the sandy clay under the coal was filled with the roots of the trees which had formed the seam. These roots ran down into the clay three or four feet and some were several inches in diameter. They were largely changed to coal but still had the appearance of roots.

In many of the beds the coal is cut by one or two systems of joints which are vertical, or nearly so, and from five or six inches to one foot and more apart. These joints are usually very clear cut and regular. On exposure to the air the lignite loses part of its moisture, begins to crack, and finally breaks up into small fragments. This change takes place much more readily in the coal of some beds than in that of others. A number of outcrops were observed in which the material must have been exposed for many months, but back several inches from the face the coal still had the appearance of being fresh and little affected by the weather. On the other hand, some beds after no longer period of exposure, show the effects of weathering for a distance of several feet from the surface.

Many of the coal beds have been burned out over large areas and there are very few which have wholly escaped burning. Some were doubtless set on fire by man, others may have caught from prairie fires, but it seems probable that spontaneous combustion has been the chief cause.

This burning of the coal beds has doubtless been going on for many thousands of years, ever since the erosion of the overlying strata brought them near the surface or exposed them in the bluffs and buttes. Once started, the fire slowly smoulders and works its way back farther and farther from the outcrop, the overlying clays settling down as the coal is consumed and the cracks thus opened admitting fresh supplies of air. (Plate XI, Fig. 2.) Thus a coal bed which is not too far below the surface may continue to burn



Fig. 1. A mass of burnt clay or clinker formed by the burning of a thick coal bed.
Mouth of Deep creek.



Fig. 2. A burning coal bed. The surface over the coal has settled down many feet and
ground is broken by wide cracks from which the gases escape.



for a long period and instances are known where beds have been on fire for at least twenty years. It seems improbable that this coal can burn very far back from the outcrop when covered by any considerable thickness of shale or sandstone, for after the coal has been consumed these would settle down and occupy its place, thus shutting off the air and smothering the fire. It seems likely, therefore, that those beds of lignite which have burned out over many square miles must have been near the surface, as we find them today, when they were being consumed.

The heat thus produced has changed the overlying clays, and either burned them to a red or pink clinker, or entirely fused them into slag-like masses. These clinker beds often have a thickness of forty to fifty feet and over and are a very conspicuous feature not only of the badlands, but of the upland prairie as well. In some instances where two coal beds are not over thirty or forty feet apart the clinker produced by each may form but a single layer, the entire thickness of intervening clays being burned. (Plate XI., Fig. 1.)

ANALYSES.

The following analyses show the composition of the brown lignite of North Dakota. The analyses were made under the supervision of N. W. Lord at the fuel-testing plant of the United States Geological Survey at St. Louis by F. M. Stanton, Chief Chemist:

	No. 1	No. 2	No. 3	No. 4
Moisture	43.78	29.78	38.45	28.09
Volatile combustible	26.07	32.31	28.02	37.78
Fixed carbon	26.33	31.35	27.84	27.86
Ash	3.82	6.56	5.69	6.27
Sulphur .....	.61	.88	.54	.72

No. 1. The 35-foot bed on Sand creek, section 31, T. 135, R. 101, Billings county.

No. 2. The 21-foot bed in Sentinel Butte.

No. 3. The 9-foot bed mined at Medora.

No. 4. Near Cartwright, McKenzie county.

Both ultimate and proximate analyses were made of the coal from three North Dakota mines with the following results:¹

Brown lignite from Lehigh mine, Consolidated Coal Company, Lehigh. This sample consisted of run of mine, and was shipped under the supervision of M. R. Campbell, of the United States

¹ Bull. No. 290, U. S. Geol. Surv., pp. 135-139.

Geological Survey. Two mine samples were taken at widely separated points in the mine for chemical analysis.

	Mine samples		Car sample
Air-drying loss	35.60	33.90	10.40
Proximate { Moisture	42.06	42.81	32.64
Volatile matter	24.55	26.84	29.19
Fixed carbon	25.73	23.93	26.75
Ash	7.66	6.42	11.42
Sulphur	1.13	.96	3.54
Ultimate { Hydrogen .....	.....	.....	6.15
Carbon .....	.....	.....	39.53
Nitrogen .....	.....	.....	.49
Oxygen .....	.....	.....	38.87
Calorific value determined:			
Calories	3421	.....	3872
British thermal units	6158	.....	6970

Brown lignite from mouth of Cedar Coulee, four miles southeast of Williston, furnished by the engineers of the United States Reclamation Service. This sample consisted of run-of-mine coal. Mine sample was taken from this mine for chemical analysis.

	Mine sample	Car sample
Air-drying loss	33.10	17.30
Proximate { Moisture	41.13	36.13
Volatile matter	27.17	29.28
Fixed carbon	26.34	29.55
Ash	5.36	5.04
Sulphur .....	.72	.59
Ultimate { Hydrogen .....	.....	6.60
Carbon .....	.....	42.00
Nitrogen .....	.....	.73
Oxygen .....	.....	45.04
Calorific value determined:		
Calories	3603	4070
British thermal units	6485	7326

Brown lignite from the Wilton mine, Washburn Lignite Coal Company, one mile east of Wilton. This sample was made up of lump lignite and was shipped under the supervision of M. R. Campbell, of the United State Geological Survey. The mine samples were taken at widely separated points in the mine for chemical analysis.

		Mine samples		Car sample
Air-drying loss		32.30	33.50	12.70
Proximate	Moisture	40.53	41.88	35.96
	Volatile matter	27.05	26.11	31.92
	Fixed carbon	27.37	26.73	24.37
	Ash	5.05	5.28	7.75
Ultimate	Sulphur .....	.76	.96	1.15
	Hydrogen .....	.....	.....	6.54
	Carbon .....	.....	.....	41.43
	Nitrogen .....	.....	.....	1.21
Oxygen .....		.....	.....	41.92
Calorific value determined:				
Calories		3691	.....	3927
British thermal units		6644	.....	7069

The test of North Dakota lignite made at the Fuel Testing Plant of the United State Geological Survey at St. Louis to determine its value as a gas-producer fuel showed that it would be an ideal fuel for this purpose but for its tendency to clinker. It yielded a rich gas and not very much tar.

DETAILED DESCRIPTION OF THE COAL BEDS.

For the purpose of description the coal beds of the region may for convenience be divided into groups and these will be considered in the order of their occurrence from the lowest (oldest) to the highest (youngest). There are five such groups, namely, (1) the Yule group, (2) Great Bend group, (3) Medora group, (4) Beaver Creek group, and (5) Sentinel Butte group. (Plate XII.) Since the older beds occur in the southern part of Billings county, our description will begin with that district.

YULE GROUP OF COAL BEDS.

The coal beds belonging to this group are found in the vicinity of Yule, and are also exposed farther south on Bacon and Coyote creeks. All the beds included in this group occur in the somber beds forming the lower member of the Fort Union formation.

In following down the Little Missouri river from the southern boundary of the area no coal is found until two or three miles below the mouth of Cash creek. Here, in the southwest quarter of section 34, T. 135, R. 105, a coal bed (A) five feet thick outcrops in the steep bluff of the river, 65 feet above water level. So far as known this is the lowest workable bed outcropping anywhere in the region.

About two miles west of here the following section is exposed in some high buttes and ridges in the west half of section 32, T. 135, R. 105.

	Feet Inches	
Clinker layer formed by burning of a coal bed.....		
Shale and sandstone, mostly light gray and buff	85	
Coal, with 6-inch clay seam one foot below top ..	5	6
Shale and sandstone	25	
Coal	4	8
Shale and sandstone, to river	130	

The upper of the three coal beds represented in the above section has been largely burned out in this vicinity and no measurement of it could be secured. The lower bed may be the same that outcrops two miles east of here, but this was not definitely determined.

Three miles below the mouth of Cannon Ball creek, in section 16, T. 135, R. 105, no less than seven workable coal beds are exposed on the west side of the Little Missouri river. The section here is as follows:

	Feet Inches	
Coal	4	8
Shale, with 8-inch coal seam	6	8
Coal	4	3
Shale and sandstone	75	
Bed F: Coal	8 to 9	
Shale and sandstone	40	
Bed E: Coal	3	
Shale and sandstone	20 to 30	
Bed D: Coal	2 to 4	
Shale and sandstone	12	
Bed C: Coal	8 to 10	
Shale and sandstone	10 to 20	
Bed B: Coal	6	
Shale and sandstone, to river level	50	

Coal bed B of the above section does not appear in the river bluffs below this point and probably dips below water level near here. The upper two coal beds were not seen elsewhere and are too high to appear in the bluffs bordering the valley of the Little Missouri. The four remaining coal beds exposed in the foregoing section, namely, beds C, D, E and F, appear at a number of points along the river between section 16 and Yule. Thus bed C, which in most places has a thickness of ten feet, outcrops near water level in the southeast quarter of section 15, the southwest quarter of section 11, and the northeast quarter of section 12, all these outcrops being on the east (or south) side of the river in T. 135, R. 105. Where ex-

posed in section 12 the bottom of the coal is below water level and the dip of the beds carries this coal under the river, so that bed C is not exposed below this point. On the west side of the river, in the northeast quarter of section 10, T. 135, R. 105, the same ten-foot coal bed (C) occurs at an elevation of fifty feet above the river and outcrops at various points for over a mile along the valley of Deer creek, which enters the river at this point. The coal in bed C is of good quality and contains no clay seams.

Beds D and E appear in the river bluffs almost continuously as far as the mouth of Bull Run creek, in section 36, T. 136, R. 105. Coal bed F appears at several points where the bluffs are high enough to reach that horizon, but south of Yule it has been largely removed by erosion over extensive areas. At the sharp bend one mile south of Yule, in the southeast quarter of section 36, T. 136, R. 105, this bed is well shown toward the top of the river bluffs. In some places the coal is overlain by one to ten feet of clay, on which rest twenty-five to thirty-five feet of sand and gravel. In other places the gravel, locally hardened into a conglomerate lies directly on the coal.

At Yule, in the bluffs of Williams creek, in section 25, T. 136, R. 105, and section 30, T. 136, R. 104, the coal bed F occurs at an elevation of 110 feet above the river and is six feet thick. It extends up Williams creek four or five miles and is exposed in section 16, T. 136, R. 105, where it has the same thickness.

The beds in the vicinity of Yule have a marked dip to the northeast and this carries the coal beds down toward river level. Where the bed F appears in the steep bluff on the east side of the river, in section 29, T. 136, R. 104, it is eight feet thick and only forty feet above the river. The same bed is well exposed one mile northeast, in the southwest quarter of section 21, where the following section is found:

	Feet	Inches
Clay	7	
Coal	15	
Clay, brown, carbonaceous	9	
Coal, with one-inch clay seam 5 feet 6 inches above bottom	9	8
Sand and clay, to river	43	

This bed again outcrops one and a half miles below here, in section 17. In the southern part of the section seven feet of coal are exposed above water level, but half a mile below this coal bed F disappears below the bed of the river and is not again seen.

The somber beds are well exposed on Bacon creek, near the southern border of Billings county, and the thick bed of coal outcropping on the latter creek occurs in these strata. The coal is exposed at the T Cross ranch, in the southern part of section 20, T. 133, R. 104, where it has a thickness of twenty-eight feet above the creek bed and the total thickness is said to be thirty feet.

About seven miles south of here, on Coyote creek in Bowman county, in section 30, T. 132, R. 104, what is probably the same bed is found. Only twelve feet of coal are exposed at this point, the lower portion being covered by talus and deposit from the creek. Three miles west of the above outcrop a bed five feet six inches thick appears along the creek. The coal bed exposed on Bacon and Coyote creeks lies well toward the top of the somber beds and it is perhaps to be correlated with bed F, but this could not be determined with any degree of certainty.

THE GREAT BEND GROUP.

The coal beds of this group occur along the Little Missouri river from the vicinity Yule to the north line of township 138, one mile above the mouth of Garner creek, although all the beds of the group do not extend the entire distance of nearly thirty miles. They are also found on Deep, Sand, Bullion and other creeks emptying into the river along this portion of its course. This group of beds lies in the lower 150 feet of the light colored, middle, division of the Fort Union, and just above the somber beds which contain the Yule group.

Two miles east of Yule, on the east side of the river, in sections 21 and 28, T. 136, R. 104, two thick beds of coal occur in the upper strata exposed here, the section being as follows:

	Feet Inches
Bed I: Coal at 200 feet above river	8 to 10
Shale and sandstone	35 to 40
Bed II: Coal	5½ to 7
Shale and sandstone, to river	160

The lower of these two beds, H, outcrops below here in the northeast quarter of section 17, and the northeast quarter of section 9, of the same township and range. Several miles farther down the river, on the north side, in the northeast quarter of section 1, T. 136, R. 104, the following beds are exposed:

		Feet	Inches
Bed I	Coal		8
	Clay	1	4
	Coal	2	4
	Clay	3	
	Coal	1	
Shale and sandstone		35	
Bed H: Coal		5	6
Shale and sandstone		70	
Bed G: Coal, overlain by brown clay		4	6

The two upper beds, H and I, appear again in section 5, T. 136, R. 103, where the upper is five feet thick and the lower six and a half feet. All three beds of this group are exposed in the bluff on the north side of the river in section 3, T. 136, R. 103, across from the J. H. Follis ranch. The section here is as follows:

	Feet	Inches
Bed I: Coal	8	8
Shale and sandstone	10	
Bed H: Coal	5	2
Shale and sandstone	55	
Bed G: Coal	5	6
Shale and sandstone	80	

These beds are again exposed three miles below, in the east half of section 1, T. 136, R. 103, where, across from the Tyler ranch, the following section is well shown:

	Feet	Inches
Shale and sandstone	25	
Coal	1	6
Shale	2	
Bed I: Coal	11	6
Shale	4	6
Bed H: Coal	5	4
Sandstone	7	8
Coal	1	2
Shale	7	6
Bed G: Coal	6	10
Unexposed to river, about	70	

One-half mile north of this section and on the opposite side of the river only two coal beds occur, beds H and I having apparently become one by the thinning out of the intervening clay. The section here, near the north line of section 1, T. 136, R. 103, is as follows:

	Feet	Inches
Coal	2	
Shale and sandstone	20	
Beds H and I: Coal	17	6
Clay	1	
Coal	1	3
Clay	3	5
Coal		2
Clay	4	9
Coal		3
Clay		20
Coal		8
Clay, brown, carbonaceous		27
Bed G: Coal	5	6
Shale and sandstone, to river	35	

One mile southeast, in the southwest quarter of section 6, T. 136. R. 102, the three coal beds are present, though the upper one, I, has been burned out in the face of the bluff. The section here is:

	Feet	Inches
Clinker formed by burning of coal bed I		
Shale, buff	30	
Bed H: Coal	5	6
Shale	10	
Bed G: Coal	7	8
Shale and sandstone, to river	75	

One mile east, in the lower part of the Tepee Butte section, given on a previous page, the three coal beds each contain clay seams as shown in the following section:

	Feet	Inches
Bed I {	Coal	1 4
	Clay	3
	Coal	6
	Clay	6
	Coal	9 4
Sandstone and shale	31	
Bed H {	Coal	2 2
	Clay	2
	Coal	2 8
Sandstone and shale	22	
Bed G {	Coal	10
	Clay	6
	Coal	1 6
	Clay	2
	Coal	3 2
	Clay	1
	Coal	1 8
Shale and sandstone, to river	85	

A little over one and a half miles southeast of the above section, in the southwest quarter of section 9, T. 136, R. 102, and opposite the mouth of Sand creek, only the two upper coal beds appear. While the lower bed, G, may be present, it does not outcrop, since the strata forming the lower part of the bluff are largely unexposed.

	Feet	Inches
Bed I: Coal with 9-inch seam 5 feet above base..	21	6
Shale	22	
Bed H: Coal, with 3-inch clay parting 13 inches below top	6	10
Shale and sand, mostly unexposed, to river	105	

It will be seen from the foregoing sections that there are three workable coal beds outcropping in the bluffs of the Little Missouri river for ten miles above the mouth of Sand creek, the upper (I) being the thickest and varying from nine to twenty-one feet.

Bed H is exposed two and one-half miles below the mouth of Sand creek, in the northwest corner of section 11, T. 136, R. 102. The upper bed, I, is here represented by a layer of clinker formed by its burning, and fourteen feet below is the bed H, which shows the following section:

	Feet	Inches
Coal with 2-inch clay parting 2 feet below top	7	4
Clay	2	4
Coal		9
Clay	3	3
Coal	3	2
Clay		2
Coal	1	9

In section 2, about one-half mile below, in the bluff of the Little Missouri, the upper coal bed, I, lies 135 feet above the river and measures 11 feet 4 inches in thickness, while forty feet below is the bed H, which is 5 feet 4 inches thick. These same beds appear in the following section, which is found on the west side of the valley in the northeast quarter of section 36, T. 137, R. 102:

	Feet	Inches
Sandstone, fine-grained, argillaceous, to top of bluff.	20	
Coal	3	4
Sandstone, fine-grained, argillaceous	7	7
Clay	1	
Coal		1
Clay, gray		18

Coal	3		
Clay	3	1	
Bed I {	Coal	14	
	Clay	3-4	
	Coal	10	6
	Clay	2	
	Coal	5	1
Shale	33		
Bed H: Coal	3	8	
Unexposed to river	24		

Coal bed H does not appear in the bluffs of the Little Missouri below this point, since the dip of the strata carries it below river level, and only one thick bed of coal (I) is present. But the beds of this group occur on Third, Second and Sand creeks, where there are many outcrops.

All three beds of the Great Bend group appear on Third creek. The presence of the upper bed, I, is made known largely by the layer of clinker formed by its burning along the outcrop, this clinker horizon being traceable for many miles up the creek. The middle bed, H, outcrops in sections 33 and 35, T. 137, R. 101. In the former locality the section of the bed is as follows:

	Feet	Inches
Coal	6	
Clay	6½	
Coal	7	

In section 35 the following section is exposed:

	Feet	Inches
Coal	8	3
Clay	2	
Coal	2	

The lower of the three coal beds, G, is well exposed in the cut bank on Third creek, in section 4, T. 136, R. 101, where the following section appears:

	Feet	Inches
Shale	15-50	
Coal	7½-8½	
Shale	8-10	
Coal	10	
Shale	3	
Coal	3	6
Unexposed to creek	7	

The three coal beds in the above section are considered as belonging to a single horizon (G), and they lie from thirty to forty feet below the middle coal bed of the group.

Second creek empties into the Little Missouri river two miles below the mouth of Sand creek and thick beds of coal are well exposed in the valley. In a ravine tributary to the main valley, in the northwest quarter of section 12, T. 136, R. 102, the following section appears:

	Feet	Inches
Bed I: Coal	12	3
Shale	20 to 24	

One-half mile south of here in the southwest quarter of section 12, T. 136, R. 102, at the J. D. Russell ranch, the lower of the beds occurring in the above section is well shown and is here represented by three coal beds, as follows:

	Feet	Inches
Shale	10	
Bed H {	Coal, with 2-inch clay parting 5 feet below top	21 8
	Clay	18
	Coal	3 8
	Clay	11 6
	Coal, exposed above creek	7

It will be noted that the total thickness of the coal exposed in the above section is 32 feet 4 inches. The twenty-one-foot coal bed outcrops along Second creek for over a mile above this point.

One-half mile east of Mr. Russell's house, in the southeast quarter of section 12, the upper coal bed (I), which is twenty-four feet above that just given, is well shown as follows:

	Feet	Inches
Shale, sandy	10	
Bed I {	Coal	7 6
	Clay	3
	Coal	12
	Clay	6
	Coal	5½
	Clay	5
	Coal	2 10

One and a half miles south of the Russell ranch, at the Geo. Clark ranch on the Dry Fork of Sand creek, in the west half of section 24, T. 136, R. 102, the following section is shown along the creek:

	Feet	Inches
Shale	12	
Coal	7½	
Clay	2	
Coal, with 1-inch clay parting 5 feet below top; base of coal is at creek level	12	

Between one and two miles south of here, in the southeast quarter of section 26, T. 136, R. 102, the following section is exposed:

	Feet	Inches
Shale	10-15	
Coal	8	3
Clay	2	4
Coal	10	4
Sandstone	3	
Coal, with 2-inch clay parting	5	4
Shale, exposed to creek bed	6	

These are doubtless the same coal beds as those outcropping at the Clark ranch, except that at the latter place the lower coal does not show above the bed of the creek. At both localities the horizon represented is probably that of bed H. (Plate XIII., Fig. 2.)

About one mile above the mouth of Dry Fork, in the northeast quarter of section 22, T. 136, R. 102, the bed I is exposed in the bluff bordering the valley. It is here 20 feet 3 inches thick and a section of the coal is as follows:

	Feet	Inches
Coal	7	3
Clay	10	
Coal	9	10
Clay	4	
Coal	2	

This coal is burned out extensively in the vicinity and is represented by a thick layer of clinker. In the northwest quarter of section 22, T. 136, R. 102, at the junction of Dry Fork and Sand creek valleys, the following section occurs:

	Feet	Inches
Clinker layer, formed by burning of coal bed I	10	
Shale, gray, sandy	24	
Shale, brown	16	
Coal	2	4
Bed H Clay	6	
Coal	2	8
Unexposed to creek	90	

Both the upper and lower coal beds, H and I, appear on the west side of the valley of Sand creek, about three miles above its mouth,



Fig. 1. Coal bed I of the Great Bend group exposed on Little Missouri near the Harmon ranch. Total thickness of coal, sixteen feet.



Fig. 2. Coal beds of the Great Bend group exposed three and a half miles southeast of the mouth of Sand creek. Aggregate thickness of coal, twenty-four feet.



Fig. 1. Coal bed thirty-five feet thick exposed on Sand creek. The lower portion of the bed is covered with talus, but the coal extends from base of picture to the top.



Fig. 2. A distant view of the 35-foot coal bed on Sand creek. Photo by A. L. Fellows.

in the southeast quarter of section 28, T. 136, R. 102. The section is as follows:

	Feet	Inches
Bed I: Coal	20	
Shale	15	
Bed H: Coal	7	8
Unexposed to creek	85	

Following up the valley of Sand creek there are few outcrops of these coal beds until the old Russell ranch is reached, in the north-east quarter of section 31, T. 135, R. 101. Here is exposed the thickest coal bed in North Dakota, so far as known, the section being as follows:

	Feet	Inches
Clay and sand wash	5-10	
Shale (Fort Union)	4-6	
Coal	3-4	
Clay	2½	
Coal	35	
Clay, to creek bed	3	

The 35-foot bed is clean coal throughout, with no clay seams. (Plate XIV., Figs. 1 and 2.) It outcrops again on the creek one-half mile south, near the south line of section 31. This thick bed of coal has burned out extensively and was traced by its clinker horizon for many miles down the valley of Sand creek. There is little doubt that this 35-foot bed is the same as the upper bed (I) that outcrops on the creek seven or eight miles below, in section 28, T. 136, R. 102, where its thickness is twenty feet; or it may be that the upper and lower beds, H and I, occurring in the lower course of Sand creek valley, have come together through the thinning out of the intervening clay, and that the 35-foot bed is formed by the union of beds H and I.

There are several other coal beds in the Sand creek district which are above the three forming the Great Bend group, but which are mentioned here since they cannot be definitely correlated with the higher beds occurring elsewhere in the region.

A coal bed five and a half feet thick outcrops on the creek at Sand-creek Post Office, near the east line of section 34, T. 134, R. 101. The following occur in Black Butte, where they are exposed near the east end, in a ravine in section 19, T. 134, R. 101.

	Feet	Inches
Coal	5	1
Clay	4	5
Coal	3	6
Clay		14
Coal	3	4

This coal is in the upper, dark colored division of the Fort Union.

Returning to the Little Missouri river, we will now trace the coal beds of the Great Bend group down the valley from the mouth of Third creek. At the sharp bend in the southwest quarter of section 19, T. 137, R. 101, near Mr. German's ranch, the upper member of the group, bed I, outcrops fifty feet above river level. It has a thickness here of sixteen feet, is overlain by twenty feet of sandstone, and contains several thin clay seams one or two inches thick. Less than one-half mile northwest of this outcrop the same bed is exposed in a ravine tributary to the river, the thickness of the coal here being 13½ feet, with a 2-inch clay seam 2½ feet above the base. This bed can be traced in the bluffs bordering the west side of the Little Missouri valley, both by its occasional outcrops and by the thick layer of clinker formed where it has burned. At the ox-bow bend in section 3, T. 137, R. 102, the coal measures 13 feet and 8 inches and lies 50 feet above the river, and its thickness at the mouth of Bullion creek is ten feet. Between four and five miles below the mouth of Bullion creek in section 18, T. 138, R. 102, the coal bed I is at water level and is 10 feet 4 inches thick. Two miles north of this point the northward dip of the strata carries this thick bed below river level and it does not appear again. Its last outcrop in going down the river is near the north line of section 5, T. 138, R. 102, about three-quarters of a mile above the Harmon ranch. (Plate XIII, Fig. 1.) The section of bed I is here as follows:

	Feet.	Inches.
Shale, buff and gray	10-50	
Shale, carbonaceous, black and brown	5	6
Coal	11	8
Clay		7
Coal		8
Clay		4
Coal, bottom of bed several inches above low water	3	6

Since the bed I is the highest of the Great Bend group, it follows that none of the members of that group is exposed north of the north line of T. 138, although they doubtless extend many miles in

that direction below river level. Bed I outcrops at various points on Bullion creek for five or six miles above its mouth. In the southeast quarter of section 1, T. 137, R. 103, about one mile above its mouth, the coal is ten feet thick; near the east line of section 11 it is nine feet; in section 13, T. 137, R. 104, it is five feet; and at the old Nollet ranch, near the east line of section 10 of the same township and range it has a thickness of five feet and lies 25 feet above the creek. No outcrops of bed I were seen west of this point, unless the coal exposed in the northeast quarter of section 9, and having a thickness of 26 to 30 inches, is this member, which grows thinner toward the west. In the northeast quarter of section 10 a lower coal bed, possibly H, has been mined on a small scale. The coal lies two feet above creek level and a thickness of three feet is exposed, but the base of the bed is not shown. It is overlain by twenty inches of brown, carbonaceous clay.

About one-half mile southeast of Alpha, near the center of section 33, T. 137, R. 104, a coal bed is well exposed on a short tributary of the Little Missouri river. The section is as follows:

	Feet.	Inches.
Clay wash	3-6	
Clay, blue	2	
Clay, brown, carbonaceous		8
Coal	6	6

Considerable coal has been mined here by the farmers of the vicinity, who work it by stripping off the cover. This coal probably belongs to bed H, which appears in the river bluffs several miles to the southeast. The former presence of a higher coal bed (I) in this district is evident from the burnt clay seen at many points.

Coal is also exposed in several places in the vicinity of Burkey, where it outcrops on Bullion creek and its tributaries. In the southeast quarter of section 5, T. 137, R. 105, seven feet of coal outcrops just above creek level, and the bottom of the bed is not exposed. The cover is ten feet thick, increasing in thickness back from the creek. The coal has been mined here for a distance of sixty feet along its outcrop. In the northeast quarter of section 8, what is probably the same bed has been mined at intervals for a distance of 100 feet along the creek. The full thickness could not be determined here, as the bottom of the coal is below the creek bed, but a measurement near by gave a thickness of 7 feet 3 inches. Coal also

outcrops two and a half miles east of Burkey, in the northern half of section 11, T. 137, R. 105, where the following section appears:

	Feet.
Coal	5
Clay	10
Coal, exposed, but not the entire thickness.....	2½

It is evident from the foregoing detailed description of outcrops that the coal beds of the Great Bend group cover a large area. This is especially apparent in the case of the thicker upper bed, whose outcrops are distributed over a more extensive area than those of the lower members of the group. This bed, I, is known to extend from the southern boundary of T. 135 north twenty-four miles to the northern line of T. 138, and from the eastern edge of R. 101, west twenty-one miles to Yule. It covered an area of at least 500 square miles and undoubtedly much more. It varies in thickness from five feet and less to thirty-five feet.

THE MEDORA GROUP OF COAL BEDS.

The members of this group outcrop along the valley of the Little Missouri river from the vicinity of Bullion Butte northward to the northern boundary of Billings county. The four beds which constitute the group have a vertical range of about 200 feet, the lower member lying some ninety feet above bed I. The two middle beds appear in the river bluffs at Medora, whence the name of the group, and the thicker one is mined at that point. The beds of this division have been designated in the vertical section by the letters J, K, L and M. Not only do these outcrop on the Little Missouri river, but they occur in the northwestern part of the region, on Beaver and Elk creeks, and on Andrews creek near Sentinel Butte station.

For convenience in description we will begin near Medora and trace the beds first south, and then north to the county line.

The following is the section of the coal beds which are present in the bluffs at Medora:

	Feet.	Inches.
Shale		
Bed L: Coal	4	6
Shale and sandstone	31	
Bed K: { Coal		2
Clay		2
Coal	8	
Clay		3
Coal		11
Shale and sandstone, to river.....	40	

The lower coal, K, has been mined here for a number of years. From six to six and a half feet of coal are removed and the remainder is left to form the roof of the mine. The entry of the present mine is about 100 feet long. This same bed was formerly mined extensively by the Northern Pacific Railway Company, their old workings being located on the west side of the river not far from the railroad bridge.

About two miles south of Medora, in the steep bluff at the mouth of Sully creek, the beds K and L are both well shown. The lower (K) is here eighty feet above the river and is $8\frac{1}{2}$ feet thick, while forty feet above is the upper bed (L) with a thickness of five feet.

The lower bed is exposed on Sully creek in the northwest quarter of section 2, T. 139, R. 102, where its thickness is nine feet, and it disappears below creek level near this point. Near the southern edge of section 1, T. 139, R. 102, the two higher beds of the Medora group appear in the side of the creek valley, the section being as follows:

	Feet.	Inches.
Shale and sandstone		
{ Coal	3	2
Bed M: { Clay, brown and carbonaceous below . . .	5	6
{ Coal	4	4
Sandstone, massive, with some shale above.	60	
Bed L: Coal	5	
Clay, to creek bed	10	

The upper coal bed, M, is represented in many places by a single bed.

In the bluff of the Little Missouri river at the Custer Trail ranch, in section 10, T. 139, R. 102, the following exposure occurs:

	Feet.	Inches.
Bed M: Coal	2	$\frac{1}{2}$
Shale and sandstone	30	
Bed L: Coal	4	
Shale and sandstone	45	
Bed K: Coal	6	$\frac{1}{2}$
Unexposed to river	95	

One and a half miles south of here, in the northeast quarter of section 22, three coal beds are exposed in the river bluff, as follows:

	Feet.	Inches.
{ Coal	1	6
Bed K: { Clay, brown	6-11	
{ Coal	6	6
{ Clay, brown	1	
{ Coal	6	

Shale and sandstone	32	
Bed J: Coal	7	6
Shale and sandstone	21	
Coal	4	
Shale and sandstone, to river	45	

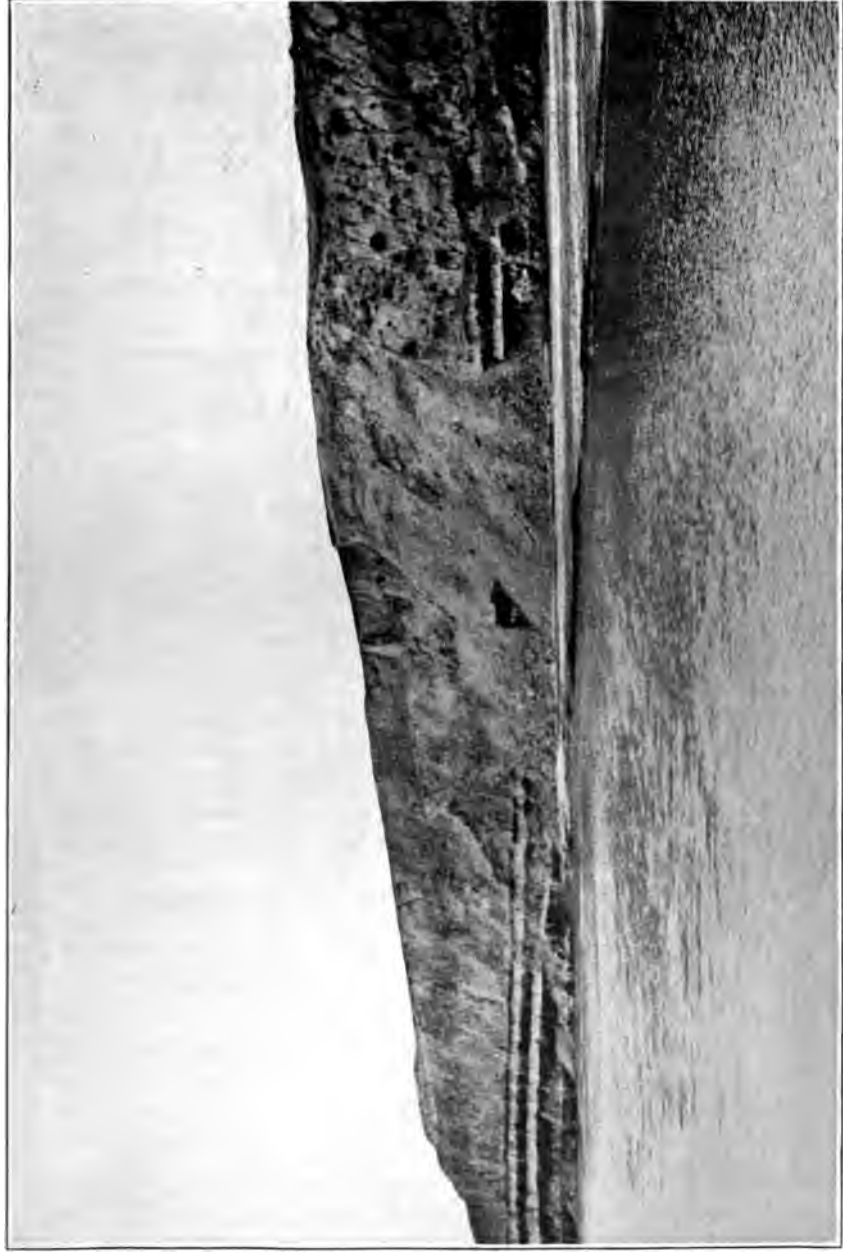
The lowest coal bed of the above section does not appear elsewhere and is probably only a local seam.

Bed K also outcrops in the northeast quarter of section 6, T. 138, R. 102, where it lies at an elevation of 125 feet above the river and is seven feet thick. About thirty-five feet above K is a bed three to four feet thick which is probably L. No more outcrops of these beds were observed in going up the river until Bullion Butte was reached. Here, in a ravine on the north slope, in section 12, T. 137, R. 103, the following coal bed is exposed:

	Feet.	Inches.
Coal	4	4
Clay	4	
Coal	3	10

This coal lies about 180 feet above the river and probably is to be correlated with bed K of the Medora group. Five miles to the east, in the southwest quarter of section 2, T. 137, R. 102, what is doubtless the same bed occurs in the river bluff. It has a thickness of six to eight feet and is 200 feet above water level. In the divide south of Bullion creek, between the latter and the Little Missouri, there is a coal bed five feet thick which belongs to the same group. South of Bullion Butte and of the high divide just mentioned the members of the Medora group do not occur, since the surface of the plain is below their horizon.

North of Medora these beds outcrop at frequent intervals for many miles along the valley of the Little Missouri. They are well exposed where the river swings against the bluff near the center of section 15, about two miles north of the railroad. Here the bed K is six to eight feet in thickness and lies fifty feet above the river, while thirty feet higher is the coal bed L with thickness of four feet. The two beds approach each other toward the north and northeast, and in the bluff in the northeast quarter of section 10 they are not over twelve feet apart. The lower outcrops on Knutson creek for about two miles above its mouth, measuring $7\frac{1}{2}$ feet in thickness. Both are well exposed on the river in the northeast corner of section 11, across from the Burgess ranch, where the following section is well shown:



Coal beds of the Melora group exposed on Little Missouri river near the mouth of Ash creek. Total thickness of coal, sixteen feet and five inches.

	Feet.
Bed L: Coal	4½
Shale and sandstone	11
Bed K: Coal exposed above water level of the river, but extends below this.	8

These two beds outcrop across the river, in a cut bank on Pad-dock creek, in the northwest quarter of section 12, where only the upper foot or two of the lower coal is exposed, overlain by 12 feet of sandstone and clay and the 5-foot upper coal bed.

A short distance below the outcrop across from the Burgess ranch the two beds of coal dip below river level, but reappear again about two miles to the north, in the northeast quarter of section 32, T. 141, R. 101. Here, in the cut bank on the west side of the river, the following section appears:

	Feet.	Inches.
Clay		
Coal		2-4
Clay	1½-2	
Bed L: Coal	4½-5	
Sandstone, firmly laminated, passing below into clay..	8-10	
Bed K: Coal, only the upper part of the bed is shown here, and exposed thickness is.	2	

For over ten miles north of this exposure these two beds are below the river, and no workable coal is present in the bluffs of the Little Missouri, but the beds K and L are probably not far below the bottom of the valley, for they again appear farther down stream.

In the southwest quarter of section 11, T. 142, R. 102, the following section is well exposed in the steep cut bank on the east side of the river:

	Feet.	Inches.
Clay wash	4-6	
Clay, sandy	6-8	
Coal	1	
Clay	5	6
Coal	3	
Clay, sandy	6	
Bed K: { Coal	6	
{ Clay, sandy	3	6
{ Coal	6	5
Clay exposed above river	1	

Total thickness of coal, 16 feet 5 inches. (Plate XV.)

Three miles below, in the northern half of section 35, T. 143, R. 102, a coal bed sixteen feet thick outcrops on the river. (Plate

XVI., Fig. 1.) Less than one mile below, in the southeast quarter of section 27, T. 143, R. 102, the following section is well shown:

	Feet.	Inches.
Sandstone, fine-grained, gray and buff.....	10	
Sandstone, argillaceous, fine-grained and finely laminated, contains many iron pyrites nodules.....	2	6
Bed L: Coal	2	10
Clay		10
Bed K: { Coal	3	4
{ Clay		10
{ Coal	7	7
Sandstone, argillaceous, fine-grained and laminated, contains many iron pyrites nodules and some carbonized roots running down from coal, exposed above river..	4-5	

The three coal beds of the above section probably represent, as indicated, K and L, the clay separating the upper and lower coal having thinned to only ten inches and the lower bed (K) being divided by a ten-inch clay band.

In the extreme northeast corner of section 21, T. 143, R. 102, less than two miles below the last-mentioned outcrop, the same beds are exposed in the river bluff, and a lower bed of coal appears, the section being as follows:

	Feet.	Inches.
Sandstone		
Bed L: Coal		31
Clay		10
Bed K: { Coal	3	2
{ Clay		8
{ Coal	6	8
Sandstone, argillaceous, fine-grained	40	
Bed J: Coal, partly under water	3½-4	

The lower bed, J, is a lower coal which does not appear along the Little Missouri between Medora and this point, but which was traced from here to the mouth of Beaver creek.

Continuing down the river one mile another good exposure of the coal beds is found in the steep bluff on the east side of the river near the west line of section 15, T. 143, R. 102 (Plate XVI., Fig. 2), the section being as follows:

	Feet.	Inches.
Shale and sandstone		
Bed K and L: Coal, with three clay partings 1 to 3 inches thick in upper half of the bed		10
Sandstone and shale		30
Bed J: Coal		32-34
Clay, exposed to water level	2-6	



Fig. 1. Coal bed sixteen feet thick, two miles southeast of mouth of Roosevelt creek, in section 35, T. 143, R. 102.



Fig. 2. Two coal beds about one mile below the mouth of Roosevelt creek, in section 15, T. 143, R. 102. The upper bed is ten feet thick.

The coal beds K and L, which have been approaching each other through the thinning of the intervening clay, here unite to form one thick bed with, however, several clay partings, which farther north thicken in places and split the coal into several seams. This is well shown in the northeast corner of section 17, T. 143, R. 102, where the same coal beds are well exposed, as follows:

	Feet.	Inches.
Sandstone, argillaceous	12	
Clay	3	
Bed K and L: {	Coal	2
	Clay	4
	Coal	8
	Clay	1
	Coal	2
	Clay	7
	Coal	5 6
Sandstone, massive, with some clay	30	
Bed J: Coal		32
Sandstone and shale, to river level	30	

The upper coal with three clay seams corresponds to the ten-foot bed of the preceding section formed by the union of K and L.

This same upper coal horizon outcrops in the river bluffs two miles to the north in the southwest quarter of section 33, T. 144, R. 102, across the river from Roosevelt's old Elkhorn ranch, the section here being as follows:

	Feet.	Inches.
Clay		
Coal		8
Clay	1	
Bed L: Coal	4	
Sandstone	5	6
Bed K: {	Coal	8
	Clay	3 6
	Coal	1
	Clay	1 6
	Coal	4
Unexposed to river, about	50	

The lower bed is not exposed at this point.

The splitting up of the coal into many beds by clay seams is well illustrated in this section. There is no doubt that this is the same horizon which both to the north and south of here is represented by a single thick bed of coal.

Less than one and a half miles below the above outcrop, in the west half of section 27, T. 144, R. 102, the following section occurs:

	Feet.	Inches.
Sandstone, massive		
{ Coal	1	
{ Clay		8
Bed K and L: { Coal	3	
{ Clay		15-40
{ Coal		15
Sandstone and clay; sandstone massive, fine-grained and laminated	27	
Coal		6
Sandstone	3	
Bed J: { Coal		10
{ Clay		8
{ Coal, bottom of bed at river level	5	

The rapid variation in the thickness of the clay seams is well shown in this exposure, where within a distance of a few hundred feet the lower clay in the upper coal varies from fifteen to forty inches.

About three miles to the north, in the southeast quarter of section 9, T. 144, R. 102, the same two beds of coal appear as in the following section:

	Feet.	Inches.
Shale and sandstone, to top of bluff		
Coal		26
Shale and sandstone with several thin coal seams, 1 to 3 inches thick	27	
Sandstone ledge	4-5	
Clay, sandy, with thin coal seam	2	
Bed K and L: { Coal	5	8
{ Clay		6-10
{ Coal	1	
Shale and sandstone	25	
Bed J: Coal	3	2
Clay, to water level		20

These coal beds outcrop again on the west side of the valley, about one quarter of a mile south of the mouth of Beaver creek, in section 6, T. 144, R. 102. (Plate XVII., Fig. 2.) Here in the bluff of the river the following section is exposed:

	Feet.	Inches.
Shale and sandstone to top of bluff with several thin coal seams, about	150	
Bed K and L: { Coal	7	10
{ Clay, passing above into coal	6	6
{ Coal		13-15
Shale	15	
Coal		10-12
Clay, blue		20
Sandstone, fine-grained	10	
Bed J: Coal		38-40
Shale, to river bed	14	1



Fig. 1. Many thin beds of coal exposed in the bluffs of the Little Missouri several miles above the mouth of Ash creek.



Fig. 2. Coal beds of the Medora group exposed on Little Missouri river just above the mouth of Beaver creek. Upper coal bed eight feet thick.

Coal on Beaver Creek. The two thick coal beds of the above section were traced up the valley of Beaver creek for a distance of four or five miles. They are exposed one mile above the mouth, in the southwest quarter of section 34, T. 145, R. 102, McKenzie county, where the following section appears:

	Feet.	Inches.
Sandstone	10	
Bed K-L: Coal	6	7
Sandstone and shale	43	
Bed J: Coal		35
Shale	8	
Sandstone, to creek bed	21	

Three miles above the mouth of Beaver creek, in the southwest quarter of section 2, T. 144, R. 103, there are several cut banks along the stream where the beds are well shown, as in the following section:

	Feet.	Inches
Sandstone and shale to top of bluff	35	
Coal	20-24	
Shale	18	6
Shale, brown, carbonaceous		3
Shale and sand	32	6
Bed L: Coal	4	8
Shale	4	8
Bed K: Coal	3	4
Shale, passing into sandstone above	5	2
Coal		15
Shale, blue	6	6
Shale, black, carbonaceous		0
Coal		3
Shale, sandy	8	
Coal		8
Sandstone	15	6
Bed J: Coal	3	5
Clay, to creek bed	1-2	

Beds K and L undoubtedly represent the single thick upper coal bed appearing on the creek two miles below and also at many points in the bluffs of the Little Missouri. The three thick coal beds of the above section also outcrop about one mile to the southwest, near the south line of section 10, where the lower coal (J) has a thickness of four feet. (Plate XIX., Fig. 1.) The exposure of the beds in a bluff on the creek near the north line of section 22, T. 144, R. 103, is as follows:

	Feet.	Inches.
Sandstone, massive	65	
Bed L: Coal	2	3
Clay	1	6
Bed K: Coal	2	4
Clay, blue	3	2
Clay, black, carbonaceous	8-10	
Coal	4	
Sandstone, passing above into shale	7	2
Coal	1	6
Clay	8	
Coal		2
Clay	1	
Bed J: Coal	5	6
Clay	10	
Coal	8	
Clay, to creek level	1	

It will be noted that the lower coal bed (J) has thickened toward the south from 3 feet 5 inches in section 2 to 5½ feet two miles distant. It does not outcrop on Beaver creek above this point but passes below the bottom of the valley, the rise of the surface carrying it above the horizon of this bed. On the other hand, the beds K and L have become thinner toward the south and the thinning of the intervening clay has brought them closer together.

The section of the strata in the high bluffs near the south line of section 22 shows a succession of beds quite different from anything seen below this point on Beaver creek. It is as follows:

	Feet.	Inches.
Coal	1	8
Sandstone	10	
Clay, black and carbonaceous below, sandy above	5	
Coal		3
Clay, carbonaceous at bottom	2	
Coal		8
Sandstone, stained with iron, with some shale	20	4
Coal	2	
Shale	7	
Coal	1	3
Clay	2	6
Coal, impure, clayey	1	8
Shale, sandy	18	8
Bed M: Coal	4	
Clay	4	3
Coal, impure		2
Shale, sandy, carbonaceous layer 4 inches thick near		



Fig. 1. Three coal beds of the Medora group which outcrop on Beaver creek in section 10, T. 144, R. 103. Aggregate thickness of upper two beds is eight feet.



Fig. 2. Bluff on Beaver creek, in section 22, T. 144, R. 103, showing ten coal beds. The thickest coal bed measures four feet and four inches.

	Feet.	Inches.
middle	8	
Coal	2	10
Clay	4	6
Coal	2	4
Sandstone and shale	9	6
Coal	1	6
Sandstone and shale	17	4
Bed K-L: Coal	4	4
Clay		6
Coal		6
Clay, sandy	2	3
Coal		10
Clay and sandstone	6	
Coal		8
Clay and sandstone to creek level	16	

It will be noted in the above section that there are fifteen coal beds outcropping in this bluff and ten of them appear in the accompanying picture. (Plate XIX., Fig. 2.) There are only two, however, beds K-L and M, which are of workable thickness. Of these two, the lower is believed to represent the beds K and L, it having been found that in places these approach each other and even unite to form a single bed. The upper of the two thick beds corresponds in position to the uppermost of the Medora group and is probably to be correlated with coal bed M. The two thick beds shown in the above section and the three thinner ones between them outcrop above here at frequent intervals for a distance of about six miles in the bluffs bordering Beaver creek.

They are well shown in the southeast quarter of section 32, T. 144, R. 103, near the Moore ranch, where the following beds occur:

	Feet.	Inches.
Sandstone	4	3
Coal	1	3
Shale and sandstone	14	
Coal		4
Sandstone, argillaceous	6	
Clay, black, carbonaceous		4
Clay	5	6
Coal		8
Clay, sandy	5	
Bed M: Coal	5	2
Sandstone and shale	16	
Coal	1	4
Sandstone and a little shale	21	

	Feet.	Inches.
Coal	2	
Sandstone .....	.5	10
Coal	2	
Shale	6	
Coal .....	..	2
Shale	9	
Bed K-L: Coal, base at creek level.....	5	8

The lower coal bed (K-L) outcrops on the creek in the northwest corner of section 6, T. 143, R. 103, where the base of the coal is below the bed of the creek, but it is not exposed along the valley above this point, since the coal passes below the bottom of the valley. But the uppermost member of the Medora group (M) is seen in the bluffs bordering the valley of Beaver creek as far as the McQuillon ranch, in section 20, T. 143, R. 104. It will be mentioned again in connection with sections showing the coal beds of the Beaver Creek group.

In the valley of Elk creek, a tributary of Beaver which enters it from the south in the southwest quarter of section 11, T. 143, R. 104, only one workable coal bed is exposed. This is probably the one that appear fifty feet above creek level at the junction of Beaver and Elk creeks, and in that case is the upper member of the Medora group, or bed M. It outcrops in the northwest quarter of section 1, T. 142, R. 104, where the following section occurs:

	Feet	Inches
Sandstone, massive, to top of bluff	20	
Coal		8
Clay, blue		8
Bed M: Coal	4	6
Clay		6
Coal		4
Sandstone and shale above creek bed	25	

Where the coal bed M outcrops in the northwest quarter of section 14, T. 142, R. 104, it is six feet thick and one mile west it measures five feet ten inches. It is this bed which is mined near the old T D (now the Wilson) ranch, the mine being in the northwest quarter of section 21, T. 142, R. 104. The base of the coal does not show here, but it is at least five feet thick. The mine is in the bottom of the valley of Elk creek and the coal is obtained by stripping off the cover, which is here only a few feet thick.

Near the J. B. Bird ranch on Wannigan creek, in section 34, T. 142, R. 103, a bed of coal 3 feet 9 inches thick is exposed. This is probably bed M.

The upper coal bed of the Medora group, M, also outcrops on Andrews creek at several points between two and three miles east of Sentinel Butte. In the southwest quarter of section 21, T. 140, R. 104, the section is as follows:

	Feet	Inches
Sandstone, soft, yellowish	20	
Coal	5	2
Clay	5	6
Coal	1	
Clay	5	6
Coal	1	6

The coal is mined here on a small scale during the winter for local use. A little over one mile below here, in the southeast quarter of section 22, T. 140, R. 104, there is another exposure of the same bed as follows:

	Feet	Inches
Clay		6
Coal	1	6
Clay, bituminous		4
Coal	5	

Summarizing the data of the foregoing sections it is seen that the two middle beds of the Medora group, K and L, are 45 feet apart near the Custer Trail ranch, and the lower of the two is about 100 feet above the Little Missouri. They dip to the north and are carried below river bed level a few miles beyond the Burgess ranch. They also approach each other in the same direction, being 35 feet apart at Medora and only eight feet apart opposite the mouth of Jewell creek. Then for nearly ten miles these coal beds are below the river and do not reappear until near the mouth of Ash creek. The three beds exposed here are believed to represent K and L, and the thick upper coal bed occurring in the river bluffs between Ash creek and the northern boundary of Billings county, sometimes split into several by clay seams and sometimes forming a single bed with no partings, is undoubtedly the same horizon. Near the mouth of Roosevelt creek a lower coal bed, J, appears and continues above river level to the mouth of Beaver creek and beyond.

It will thus be seen that from near the Custer Trail ranch to the northern limits of the area two workable coal beds of the Medora

group are present in the bluffs bordering the Little Missouri, the only place where they are below water level being the ten miles between Jewell and Ash creeks.

All four members of the Medora group occur on Beaver creek, but they disappear successively below the bottom of the valley, bed K and L near the south line of T. 144, R. 103, and bed M continuing to within six miles of the Montana line. The latter coal bed also appears on Elk creek as far up as the Wilson ranch.

BEAVER CREEK GROUP OF COAL BEDS.

The coal beds of this group are exposed in the northwestern corner of Billings county, along the valley of Beaver creek and its tributaries. They lie above the beds of the Medora group and the uppermost member is about 100 feet below the Sentinel Butte group. No workable beds of coal at this horizon were found elsewhere in the area under discussion.

In following up the valley of Beaver creek the lowest member of the group, N, first appears near the Keen ranch, in the northeast quarter of section 2, T. 143, R. 104, where the following succession of strata is exposed:

	Feet	Inches
Bed N: Coal	5	
Shale and sandstone	42	
Bed M: Coal	2	9
Shale	8	
Coal		13
Shale	10	
Sandstone, to creek bed	31	

The bed M is without question the upper of the two workable beds exposed on the creek for many miles below, since it was traced almost continuously by its outcrop or the burned clay bed formed by its burning. The five-foot bed of the above section therefore lies over forty feet above the uppermost coal of the Medora group.

The beds M and N of the above section are seen at many points in the bluffs bordering the valley between the Keen ranch and the mouth of Elk creek. At the junction of Elk and Beaver creeks the following section is well shown, in section 11, T. 143, R. 104.

	Feet	Inches
Shale and sandstone, to top of bluff		
Bed N { Coal	3	
{ Clay	2	
{ Coal	1	6
Shale and sandstone, not well exposed	42	

		Feet.	Inches.
Bed M	{ Coal	3	6
	{ Clay	3	
	{ Coal ..	2	
Shale and sandstone		30	
Coal		3	10
Shale, to creek bed		16	

Bed N has burned out extensively and the clinker layer formed by it shows in many places along the valley. The bed sixteen feet above the base of the section appears to be one which is not exposed elsewhere, unless it be the same coal which outcrops about five miles above, near the McQuillon ranch.

On Beaver creek about three miles above the mouth of Elk creek, the following section is exposed in the northwest corner of section 21, T. 143, R. 104:

	Feet	Inches
Bed O: Coal	6	6
Shale and sandstone	14	
Bed N: Coal	2	4
Shale	7	
Coal	2	2
Unexposed	46	
Bed M: Coal	4	
Unexposed to creek	59	

It will be noticed in the above section that a workable bed, O, is here present above coal N, and for eight or ten miles below the McQuillon ranch this has a uniform thickness of $6\frac{1}{2}$ feet and is the thickest bed appearing in the bluffs of Beaver creek valley. It is the middle bed, O, of the Beaver Creek group.

A little over a mile west of the above section the following beds appear in a steep bluff rising from the creek, in the northeast quarter of section 19, T. 143, R. 104:

	Feet	Inches
Sandstone to top of bluff	12	
Bed O: Coal, with 3-inch seam 18 inches above base	6	6
Shale and sandstone	15	6
Coal	2	
Shale	10	6
Bed N	{ Coal	20
	{ Clay	3 10
	{ Coal	2 2
Shale and sandstone	37	
Bed M: Coal	3	8

	Feet.	Inches.
Shale and sandstone	21	
Coal	2	10
Unexposed to creek bed	14	

The lowest bed in the above section is probably the same as the lower one exposed at the mouth of Elk creek.

About four miles above the last section, in the northeast quarter of section 26, T. 143, R. 105, the coal bed O is again exposed, the outcrop here being as follows:

	Feet	Inches
Bed O: Coal	6	6
Shale and sandstone	37	
Coal	3	
Shale	8	
Coal		26
Shale	4	
Coal, with 2-inch clay seam near top		29
Unexposed to creek	44	

The most westerly outcrop visited on Beaver creek was in the northwest quarter of section 34, T. 143, R. 105, three miles from the Montana line. In a steep bluff the following section is exposed here:

	Feet	Inches
Sandstone and shale to top of bluff	20	
Bed O: Coal	6	6
Sandstone and shale	22	
Coal	3	
Sandstone	10	
Coal	2	6
Shale and sandstone	36	
Coal	4	
Sandstone, exposed above creek	40	

Four beds of coal are exposed in the sides of the valley of the tributary of Beaver creek which flows through T. 142, R. 105. The thickest of these is the 6½-foot coal O, and sixty-five feet above is the upper bed of the Beaver Creek group, the bed P, which has a thickness of four feet.

It will be seen from the foregoing sections that the Beaver Creek group includes three coal beds. The lower, N, is exposed along the creek in T. 143, R. 104, and has a maximum thickness of five feet near the Keen ranch in section 2. Above here it is separated by a clay seam into two coal beds. The middle bed, O, has a uniform thickness of 6½ feet and lies about fifteen feet above N, outcrop-

ping along the creek from the McQuillon ranch in section 20, T. 143, R. 104, almost if not quite to the Montana line. The upper bed, P, has a thickness of four feet and was only seen at one point several miles south of Beaver creek.

The three coal beds occurring below bed O, above the McQuillon ranch, are so variable and unlike those farther down the creek that they cannot be correlated with any certainty with those found elsewhere.

The beds of this group undoubtedly extend back from Beaver creek for some miles to the north and south and should be struck in boring wells or in prospect holes.

Two beds of workable thickness are present on Little Beaver creek, in T. 141, R. 105. The outcrop of one of these disappears below the level of the creek about one-half mile east of the Montana line, where it is six feet thick.

The coal bed mined in the northwest quarter of section 8, T. 141, R. 105, shows the following section:

	Feet	Inches
Coal	6	6
Shale, sandy	8	
Coal	3	

The same bed is mined in the northwest quarter of section 16, T. 141, R. 105, where the following section appears:

	Feet	Inches
Coal	2	2
Clay		6
Coal		5
Clay		6
Coal	5	6

SENTINEL BUTTE GROUP OF COAL BEDS.

The coal beds of this group are the highest in the region and are thus named from the fact that at least three of the members are present in Sentinel Butte. Five coal beds are included in this division and they have a vertical range of about 300 feet. The four upper beds are in the dark strata forming the upper division of the Fort Union, while the lowest member lies forty to fifty feet below the contact of the two divisions. The coal beds of the Sentinel Butte group extend from Bullion Butte and the divide between Third and Bear creeks on the south to the divide north of Ash creek on the north, a distance of 35 miles; they extend from Sentinel Butte on the west to the divide near Fryburg on the east, a distance

of 25 miles, and how much farther east they occur was not determined. These coal beds have been extensively eroded over wide areas and they have also burned out on a very large scale. The bed which lies at the base of the upper Fort Union, R, can be readily traced by its red clinker horizon in the bluffs and ridges of the Little Missouri badlands as far as the eye can see.

The outcrops of the Sentinel Butte group south of the Northern Pacific railroad will first be discussed and later those north of the track will be considered.

Three of the coal beds of this group occur in Bullion Butte, that portion of the section containing them being as follows:

	Feet	Inches
Bed S: Coal	3	3
Shale, sandy, dark gray, contains near base many ferruginous nodules	50	
Bed R: Coal, at contact of upper and lower divisions of Fort Union	15	
Shale and sandstone	40	
Bed Q: Coal, at elevation of about 360 feet above river	5	

Coal bed R outcrops in the southeast quarter of section 12, T. 137, R. 108, near the north end of the butte, and it is also exposed near the south end in sections 29 and 30 of T. 137, R. 102. In this latter locality the coal measures 6½ feet thick and contains a three-inch clay seam two feet above the bottom. This thick coal bed undoubtedly underlies the entire butte.

About four miles southeast of Bullion Butte two very conspicuous elevations rise above the nearly vertical bluff of the Little Missouri and in these Teepee Buttes, as they are called, three high coal beds of the Sentinel Butte group occur. The detailed section of the strata at this point has been given on a previous page and only the upper part showing the coal is contained in the following section:

	Feet	Inches
Sandstone and shale to top of Teepee Buttes	52	
Bed T: Coal	4	6
Shale and sandstone	95	
Bed S: Coal	6	3
Shale and sandstone	25	
Bed R: Coal, with 2-inch clay seam two feet above bottom. Bed 400 feet above river	5	2

The lowest coal bed, Q, of this group occurs in the high divide west of Bullion Butte, between Bullion creek and the river, which

here has an easterly course. This coal lies about fifty feet below the coal bed R, and is therefore in the buff, light colored division of the Fort Union. It lies at an elevation of about 320 feet above the river and has a thickness of ten feet. It is exposed in the southeast quarter of section 28, T. 137, R. 103, and at other points in the divide. No measurement was secured on this divide of the coal bed R, at the contact of the two divisions of the Fort Union, as it has burned out over a large area and its outcrop is marked by a thick layer of clinker.

The beds of the Sentinel Butte group are known to extend at least eight miles east of the Little Missouri and probably continue considerably farther in that direction. The beds Q and R occur in the higher ridges and divides between Third and Bear creeks, in T. 137, R. 101. The coal R near the center of this township is nine feet thick and the lower bed Q, is here only fifteen feet below and is 5½ feet thick. The former bed, R, was traced by its clinker horizon several miles east of the above township, or as far as the divide between the drainage of the Little Missouri and Missouri rivers.

The lower bed, Q, is exposed on Bear creek in the southeast quarter of section 36, T. 138, R. 102, where it measures 4 feet 4 inches in thickness and lies just above creek level. The bed R outcrops for some distance along the creek three miles above here, near the southwest corner of section 34, T. 138, R. 101. The section of the coal bed is as follows:

	Feet	Inches
Coal	6	2
Clay		14
Coal		20

This is one of the few places where this bed of coal contains a clay seam, and it is generally free from clay partings. Mr. Schuyler Lebo, who has a detailed and accurate knowledge of township 138, ranges 101 and 102, states that the coal bed R outcrops in the following sections: 12, 14, 26 of T. 138, R. 102, and in 8, 10, 21 of T. 138, R. 101. This thick bed of coal underlies practically all of the latter township, except where it has been cut out by the streams. A measurement of this same bed was secured in the southeast quarter of section 23, T. 139, R. 102, where the coal is exposed near the top of the bluff at an elevation of 280 feet above the river. It here has a thickness of seventeen feet and is overlain by fifteen to twenty feet of clay.

Along the valley of Sully creek the bed R has burned out extensively and along either side of the valley its horizon is marked by a thick layer of clinker which forms a very conspicuous scenic feature of this region. This bed of coal disappears below the bottom of the valley about one-half mile east of Sully Springs. The burnt clay so abundant along the Northern Pacific railroad in the vicinity of Scoria was largely formed by the burning of this coal, although there is a higher bed which has formed some clinker. The so-called burning mine, about one-half mile south of Sully Springs, is in this same coal bed, which has been burning for many years. (Plate XI.) The only place on Sully creek where an outcrop of the coal R was found was in the west half of section 14, about one mile from the above station; the upper part of the coal is here burned and has also been eroded, so that the full thickness could not be obtained, but seven feet of coal remain. Layers of clinker indicate that there are in this vicinity two coal beds above this one. One is 150 feet and the other 240 feet above the bed R, and it is quite likely that they are to be correlated with the two higher coal beds occurring in Sentinel Butte, at the same relative distances above the coal R. No outcrops were found on Sully creek where the thickness of these upper coal beds could be measured.

West of the Little Missouri river two members of the Sentinel Butte group are present in the base of Square Butte. The lower of the two, R, is five feet thick, and twenty-five feet above, separated by sandy shale, is the upper bed, S, with a thickness of fifteen feet. This latter bed is exposed in the northeast quarter of section 9, T. 139, R. 103. East of the river this upper thick bed does not occur on Sully creek or to the south of that stream.

Between Flat Top and Sentinel buttes there is a conspicuous clinker layer formed by the burning of coal bed S. About midway between the two buttes the lower bed, R, outcrops, with a thickness of five feet, and lies 50 feet below the clinker layer.

In Sentinel Butte the three upper members of this group are present. The lower of them outcrops at several points toward the bottom where it has been mined in the northeastern base, in southeast quarter of section 5, T. 139, R. 104, and the section of the bed S is as follows:

	Feet	Inches
Clay, sandy		
Coal	14	
Clay		3
Coal	6	11

This same bed has been mined in the northwest quarter of section 7, where it is 20 feet 11 inches thick. It has also been mined in the southwest quarter of section 5, and on the south and west sides of the butte. Ninety feet above this thick one is a six-foot bed of coal. The highest member is known to occur by its clinker and no exposure was seen.

A few small areas underlain by beds R and S occur in the southeastern corner of T. 139, R. 105, where they have escaped the erosion which has removed them from much of the region. Near the center of section 25 coal has been mined by stripping, the section here being as follows:

	Feet	Inches
Clay, white		
Coal	8	
Clay		10
Coal, base not exposed	7	

This bed also occurs in the base of Rocky Butte, in section 34, but it is concealed by clinker so that its thickness could not be determined.

The bed S is present in the base of Camels Hump Butte, in sections 9 and 10, T. 140, R. 104, but the coal has burned out along its outcrop and is concealed by clinker, so that no exposure could be found.

In the divide north of Andrews creek, the two beds R and S of the Sentinel Butte group occur. Near the western edge of T. 140, R. 103, they are separated by 55 feet of the dark gray strata of the upper division and each measures $5\frac{1}{2}$ feet in thickness. Both the beds are extensively burned.

In section 35 of T. 141, R. 102, bed R outcrops at an elevation of 250 feet above the Little Missouri river, but only the upper $6\frac{1}{2}$ feet of coal is exposed to view.

The same coal bed, R, underlies the irregular plateau in sections 8, 9, 10, 16 and 17, T. 140, R. 102, at an elevation of about 275 feet above the Little Missouri river. Its outcrop is nearly everywhere concealed by clinker so that its thickness could not be determined.

In the divide between Government and Franks creeks, in T. 141, R. 101, the bed R occurs at the contact of the dark-colored strata with the buff and light gray beds below. It lies from 250 to 300 feet above the Little Missouri river and is found in the buttes which rise above the general level of the divide. In the southwest quarter of section 5 the coal is 11 feet 6 inches thick, with a 3-inch clay parting

6 inches from the bottom. In the southeast quarter of section 12 that portion of the bed which is exposed measures 16 feet and the entire thickness is probably not much more than this. The bed R is also found in the divide between Franks and Ash creeks, though it is not well exposed in that area, but north of Ash creek the coal grows thin and partings develop in the bed. Thus in the northeast quarter of section 4, T. 142, R. 101, the section of this bed is as follows:

	Feet	Inches
Coal	1	3
Clay	7	
Coal	3	

Three workable coal beds are exposed in the valley of Ash creek, in the eastern part of T. 142, R. 101. The lowest is bed R and is at the contact of the light and dark colored divisions of the Fort Union. The following section of this bed appears in the north half of section 14, T. 142, R. 101:

	Feet	Inches
Shale		
Bed R { Coal	6	8
{ Clay, gray		14
{ Coal	1	4
Shale, exposed above creek	3	

A short distance below this outcrop, and in the same section, all three of the coal beds occur in the steep bluff bordering the valley of Ash creek, the section here being as follows:

	Feet	Inches
Coal	5	
Sandstone	40	
Bed S: Coal	4-5	
Shale and sandstone	35	
Bed R: Coal	6	
Shale and sandstone, to creek bed.....	20	

The upper coal bed does not correspond in position to any bed found elsewhere and is probably of limited extent. The upper two beds also appear in the northeast quarter of section 13, T. 142, R. 101, where S is 6 feet thick and has been mined on a small scale at the outcrop. The upper bed here measures 5 feet.

Bed S is well exposed just above creek level in the northeast quarter of section 20, T. 142, R. 100, the section being as follows:

		Feet	Inches
Clay wash		2-20	
Bed S	{ Coal .....	..	6
	{ Clay .....	..	3
	{ Coal	6	
Clay, blue, exposed to creek bed		3	

Considerable coal has been mined here from the outcrop by the farmers of the vicinity, although the locality is not very accessible, being in the bottom of the valley of Ash creek and about 275 feet below the level of the upland.

Very few coal outcrops occur on Green river, in northeastern Billings county. In the southern part of T. 142, R. 99, there is considerable clinker formed by the burning of a coal bed which is perhaps the same as that mined on a small scale near the base of Saddle Butte. No measurement could be secured of this bed since it is everywhere concealed. A workable coal bed is exposed on Green river in the northeast quarter of section 16, T. 141, R. 98, where it has a thickness of 4 feet 4 inches, and a few loads of coal have been taken from the outcrop here.

Two coal beds appear along the upper course of the Knife river in the northeastern corner of Billings county. Their presence is indicated chiefly by clinker along their outcrop in the sides of the valley, but they are exposed in Hungry Mans Butte, in the southeast quarter of section 35, T. 144, R. 98. The lower bed is 3 feet thick and lies 120 feet above the river; the upper bed is 40 feet above and has a thickness of 2½ feet. Both beds are in the upper, dark colored division of the Fort Union.

Coal in the Vicinity of Rainy Buttes.—In East Rainy Butte a bed with a thickness of at least 6 feet occurs 100 feet above the base.¹ This does not represent the entire thickness of the coal, which is partially concealed, and the measurement given above is only for the portion exposed. It is very probable that the same coal bed is also present in West Rainy Butte. It is doubtless to be correlated with one of the lower members of the Sentinel Butte group.

Six or seven miles north of the Rainy Buttes, on the Cannon Ball river, and at a considerably lower elevation, two workable beds of coal occur. They are exposed not far from the east line of Billings county, where the following section appears:

¹Second Bien. Rep. N. D. Geol. Survey, p. 160.

	Feet
Alluvium	4
Sandstone	5
Clay	2
Coal	4
Clay	4
Coal	5
Clay, to water level	5

COAL IN BOWMAN COUNTY.

No workable beds of coal occur along the valley of the Little Missouri river in eastern Bowman county. The strata of the latter area are the somber beds lying below the light gray and buff division of the Fort Union and the lower portion of this dark-colored series is barren of coal except in thin seams.

The most westerly coal outcrop in the county so far as known is that on Coyote creek, between three and four miles above its mouth, in T. 132, R. 105, where a bed 5 feet 6 inches thick appears along the stream.

Three miles farther up the creek, in section 30, T. 132, R. 104, 12 feet of coal are exposed, the lower portion being covered by talus and deposit from the stream, so that the entire thickness could not be determined.

Coal outcrops at various points along the North Fork of the Grand river, in southeastern Bowman county. A bed is well exposed in the cut bank of the river two miles west of Haley, in section 27, T. 129, R. 100, the section here being as follows:

	Feet
Sandstone and sandy clay	25
Coal	6½
Sandstone, soft, exposed above river.....	4-6

The coal is mined here from the outcrop, which extends along the side of the valley for 300 to 400 yards, and is used by the settlers living in the vicinity. A bed reported to have a thickness of five to six feet is also mined four miles above, in section 19, T. 129, R. 100. Coal occurs on Spring creek, one of the chief tributaries of the North Fork of the Grand, and is exposed in section 3, T. 129, R. 101. A bed outcrops on Lightning creek, between four and five miles north of Haley and has been mined in section 5, T. 129, R. 99, by stripping off the cover. Coal is also found on Buffalo creek, and between the latter and Lightning creek.

1

The Consolidated Coal Company has a mine at Scranton, on the Chicago, Milwaukee & St. Paul railroad. The thickness of the coal bed is 22 feet and it contains no clay seams. Its depth below the surface varies from 30 to 140 feet. The mine is located a quarter of a mile from the railroad, with which it is connected by a spur.

A coal bed occurs on the South Fork of the Cannon Ball river, in the extreme southwest corner of Hettinger county, only one mile east of the Billings county line. Here, in section 31, T. 133, R. 97, 3½ feet of coal are exposed, but the bed is partly concealed and its full thickness could not be determined. It is covered by three to four feet of clay and is readily mined by stripping off the cover.

DEVELOPMENT OF THE COAL RESOURCES.

Except at a few points all mining so far carried on in the region under discussion has been by the ranchers and settlers for their own use. The coal is commonly obtained where the beds outcrop along some stream or in a bluff or butte, so that it can be mined with the least expenditure of time and labor. The beds are frequently undermined by river or creek and large masses have fallen off and line the banks, ready to be broken up and loaded into wagons. In many places these outcrops can be reached only in winter when the streams are frozen over, and much of the coal is hauled at this time of the year or during the fall.

Another common method employed is that of stripping off the overlying clay, and where the cover is not over ten or fifteen feet thick this is an easy and inexpensive way of mining. In many cases the cover grows thicker as the bed is followed back into the bluff, so that a limit is reached beyond which stripping cannot be employed.

Probably the first mine to be developed in the region was the one at Little Missouri, across the river from Medora, which belonged to the Northern Pacific railroad. Coal was mined here by the railroad as early as 1884, by means of drifts running in along the bed. Some of the old dump piles and timbers may still be seen.

Several openings have been made in the nine-foot bed at Medora, and considerable coal has been shipped from this mine to nearby towns. The newest entry runs back over 75 feet from the face of the bluff and the cars are pushed out by hand. The thick coal bed at Sentinel Butte is mined at four or five points where it is exposed near the base of the slope, the coal being taken from the outcrop.

The largest mine in the area under discussion is the one recently opened by the Consolidated Coal Company at Scranton, Bowman county, on the Chicago, Milwaukee & St. Paul railroad, to which reference has already been made on a previous page. The coal is blasted from the solid and the mine is equipped with mule haulage.

The material over the coal beds is commonly clay, which makes an insecure roof requiring careful timbering to prevent it from falling. It is therefore customary, when the bed is of sufficient thickness to allow, to leave from six inches to one or two feet of lignite to form the roof of the mine. This makes an excellent roof and one which frequently requires but little timbering except along the main entry.

Future Development.—This part of North Dakota is rapidly settling up and with the large increase of population new mines will be opened in different parts of the field. At the present time nearly every farmer and rancher mines his own coal from the nearest and most accessible bed. In the future an increasing number will obtain their coal from some mine in their vicinity.

The future development of the coal resources of the region will depend to some extent upon how widely the gas engine comes into use, and also upon the cheap briquetting of the lignite. The value of the latter as a source of producer-gas for gas engines has been demonstrated by the tests made at the Fuel-Testing Plant of the United States Geological Survey at St. Louis, where it was found that North Dakota lignite furnishes a rich gas for this purpose. If the gas engine should come into general use, as many believe it will, it would result in a greatly increased demand for this kind of coal. The successful briquetting of the lignite which would allow of its being shipped and stored for a long period without breaking down into small pieces would likewise insure its increased use as a fuel. It seems probable that a commercially successful briquetting process will be found in the near future, and when discovered it will be of great benefit to North Dakota.

**THE GEOLOGY OF NORTHEASTERN
NORTH DAKOTA**

WITH SPECIAL REFERENCE TO CEMENT MATERIALS

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INTRODUCTION.

The area under consideration includes Pembina, Cavalier, and adjoining parts of Walsh and Ramsey counties, comprising townships 157 to 164 N. and ranges 50 to 64 W., or an area of about 2,400 square miles. As may be seen from the accompanying map, the region is well provided with railroads with the exception of that portion lying to the north and northeast of Langdon, in Cavalier county. It is probable that a line will be put through this area in the near future, paralleling the Hannah branch of the Great Northern railroad and midway between it and the Walhalla branch of the same road. The completion of the Northern Dakota railroad to Concrete will also serve as a stimulus and perhaps as a connecting link.

The geology of northeastern North Dakota is of much interest because of the exceptional opportunity afforded for the study of the Cretaceous formations of the region, particularly in the many outcrops of the Pembina Mountains. The area is also of economic importance from the occurrence in it of materials suitable for the manufacture of cement. These and other considerations led the Survey to undertake as detailed a study of the region at time and funds would allow.

This area and adjoining parts of the Red River Valley in Minnesota have received in the past considerable attention from geol-

ogists. The evidences of the former existence of a great lake in the Red River Valley were observed in 1823 by Keating, the geologist of the first scientific expedition to this district;¹ in 1848 by Owen;² in 1857 by Palliser;³ in 1858 by Hind;⁴ and in 1873 by Dr. G. M. Dawson.⁵ Each of these geologists explored considerable tracts of the lacustrine area, recognizing its limits in a few places, and Hind especially described and mapped portions of the lower beach ridges. Dr. Dawson's work was in connection with the British North American Boundary Commission, and includes detailed notes of the part of this area lying between the Lake of the Woods and the Pembina Mountains.

The excavation of the valley occupied by Lake Traverse, Big Stone lake and the Minnesota river was first explained in 1868 by Gen. G. K. Warren, who attributed it to the overflow from this ancient lake. He made a careful survey of this valley, and his maps and descriptions, with the accompanying discussion of geologic questions, are most valuable contributions to science.⁶ After his death, in commemoration of this work, the glacial river that was the outlet of Lake Agassiz was named River Warren.⁷

That this lake existed because of the barrier of the receding ice-sheet was first pointed out in 1872 by Prof. N. H. Winchell.⁸

Considerable work on that part of the area of Lake Agassiz which lies in Minnesota was done by Warren Upham and reported

¹Narrative of an expedition to the source of St. Peter's river, Lake Winnepeck, Lake of the Woods, etc., performed in the year 1823, under the command of Stephen H. Long, M. S. and Topographical Engineer, London, 1825, Vol. II, p. 3.

²Report of a Geological Survey of Wisconsin, Iowa and Minnesota. Philadelphia, 1852, p. 178.

³Journals, detailed reports, etc., presented to Parliament, 19th May, 1863, p. 41.

⁴Report of the Assiniboine and Saskatchewan Exploring Expedition. Toronto, 1859, pp. 39, 40, 167, 168.

⁵Report on the Geology and Resources of the Region in the Vicinity of the Fortyninth Parallel, from the Lake of the Woods to the Rocky Mountains. Montreal. 1875, p. 248.

⁶"On certain physical features of the upper Mississippi river," American Naturalist, Vol. II, pp. 497-502, November, 1869. Annual Report of the Chief of Engineers, United States Army, for 1868, pp. 304-314. "An essay concerning important physical features exhibited in the valley of the Minnesota river, and upon their significance," with maps; Report of Chief of Engineers, 1875. "Valley of the Minnesota river and of the Mississippi river to the junction of the Ohio; its origin considered; depth of bed rock," with maps; Report of Chief of Engineers, 1878, and Am. Jour. Sci. (3), Vol. XXVII, pp. 417-431, December, 1878, (General Warren died August 8, 1882).

⁷Proc. A. A. S. Vol. XXXII, for 1883, pp. 213-231; also in Amer. Jour. Sci. (3), Vol. XXVII, Jan. and Feb., 1884; and Geology of Minnesota, Vol. I, p. 622.

⁸Geol. and Nat. Hist. Survey of Minnesota, First Annual Report, for 1872, p. 63; and Sixth Annual Report, for 1877, p. 31; Prof. Winchell also explained in like manner the formerly higher levels of the Laurentian lakes. Popular Science Monthly, June and July, 1873; and the same view is stated by Prof. J. S. Newberry in the Report of the Geological Survey of Ohio, Vol. 1874, pp. 6, 8 and 51.

in the publications of the Minnesota Geological Survey.¹ More detailed work both in Minnesota and North Dakota was undertaken later by the same geologist and the report on it was published by the United States Geological Survey.² By the cooperation of the geological surveys of the United States and Canada, Warren Upham was enabled to complete his investigations on Glacial Lake Agassiz, which were published by the United States Geological Survey and in part by the Geological and Natural History Survey of Canada.³ The report is a valuable contribution to science.

Altitudes in the lake area have also been included in another publication by the United States Geological Survey.⁴

Important observations of the beaches of Lake Agassiz farther northward along the Manitoba escarpment and near the mouth of the Saskatchewan have been made during work for the Geological Survey of Canada by Mr. J. B. Tyrrell.⁵

The Geological and Natural History Survey of Minnesota in Vol. 4 of its Final Report, 1899, considers the areal geology of Kitson, Roseau and Marshall counties, lying in the Red River Valley, and these have many characteristics in common with Pembina and Walsh counties in North Dakota. Dr. C. P. Berkey, did some work in the vicinity of Walhalla and published the results in the *Am. Geologist*, Vol. XXXV, No. 3, March, 1905. Work of a general character has been carried on in the past in this area by Prof. Babcock and Dr. Leonard of the North Dakota Geological Survey, and is reported in the First and Third Biennial Reports.

Acknowledgments are due Mr. J. M. Melsted, of Gardar, and Dr. R. C. Cliff, of Park River, for their kind assistance in providing horses for carrying on the work. Thanks are due especially to Mr. H. A. Mayo, of Walhalla, for field assistance; and many other citizens of the counties aided in the work.

¹Geol. and Nat. Hist. Survey of Minnesota, Eighth Annual Report, for 1879, pp. 84-87; Eleventh Annual Report, for 1882, pp. 137-153, with map; and Final Report, Vols. I and II.

²U. S. Geol. Survey Bulletin No. 39. The Upper Beaches and Deltas of the Glacial Lake Agassiz, pp. 84, with map.

³Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. IV, for 1889-89, Part E, Report of Exploration of the Glacial Lake Agassiz in Manitoba, pp. 156, with two maps and a plate of sections. U. S. Geol. Survey, Mono. XXV, pp. 658, 38 pl. 1896.

⁴U. S. Geol. Survey, Bulletin No. 72, Altitudes between Lake Superior and the Rocky Mountains, 1891, pp. 229.

⁵Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. III, for 1887-88, Part E, Notes to accompany a preliminary map of the Riding and Duck Mountains in northwestern Manitoba, 16 pages with map. Other papers by Mr. Tyrrell, including descriptions of portions of the Lake Agassiz beaches, are, "Post Tertiary Deposits of Manitoba and the adjoining territories of Northwestern Canada," Bulletin, G. S. A., Vol. I, 1890, pp. 395-410, and "Pleistocene of the Winnipeg Basin," *Am. Geologist*, Vol. VIII, pp. 19-28, July, 1891.

PHYSIOGRAPHY.

TOPOGRAPHY.

To the most casual observer it is apparent at once that the area may be divided into three topographic divisions, namely: the Red River Valley; the Pembina Mountains; and the high rolling prairie forming the greater part of Cavalier county. These topographic divisions are well marked and important geologically. There are no outcrops of the sedimentary series in either the first or last divisions while the Upper Cretaceous formations are well exposed in the Pembina Mountains. In the Red River Valley and in Cavalier county geological field work must be confined for the greater part to the consideration of well records, and the study of the physiographic features and the glacial geology.

The Red River Valley in North Dakota lies in general between the Red River or eastern boundary of North Dakota, and range 56 W. The slope of the valley to the north in this area along the eastern boundary of the state is about $1\frac{1}{2}$ feet per mile. Going to the west along the southern boundary of Pembina county the valley bottom rises about ten feet per mile, although the ascent through the first half is only about 3 feet per mile. In the next 8 miles the surface rapidly ascends nearly 400 feet more, as one climbs the Pembina Mountain escarpment, which forms the western boundary of the valley. Along the international boundary the surface rises about 40 feet in 15 miles from Pembina to Neche, and 187 feet in the next 21 miles to the base of the Pembina Mountains. Here as before, the Cretaceous escarpment, known as the Pembina Mountains, rises abruptly, giving an elevation of 1,400 feet above the sea, and rising about 400 feet in two miles. See Plate XX, Fig. 1.

From the foregoing it will be seen that the Red River Valley is a large nearly level plain, which slopes slightly downward to the north and upward to the west. In traversing it from east to west, however, it is at once apparent that there are upon the surface certain ridges, which extend in a general north and south direction. These usually have only a slight difference in elevation from the valley, commonly 10 to 20 feet on the side towards the Red river, and 3 to 10 feet toward the west; and vary in width from 10 to 25 rods. There are also step-like terraces which extend longitudinally in a north and south direction and slope upward to the west



Fig. 1. Escarpment of the Pembina Mountains in the distance with the level plain of the Red River Valley in the foreground.



Fig. 2. Notch in the Pembina delta cut by Pembina river southeast of Walhalla. The left of the illustration shows the gentle slope to the abrupt eastern edge of the delta.



to a height of 10 to 25 feet. Besides these variations from the general level, there is also one of considerable topographic and economic interest which borders the Pembina Escarpment and is cut by the Pembina river. This is known as the Pembina delta. See Plate XX, Fig. 2.

Previous geological work in the Red River Valley has shown that this valley existed previous to the Glacial Period. During the retreat of the ice-sheet a large body of water was held in this valley by virtue of the presence of the ice-sheet to the north. This is known as Glacial Lake Agassiz. During the early part of the existence of this lake, its outlet was to the south, through the valley now occupied by Lake Traverse and Big Stone and the Minnesota river. As the ice-sheet receded to the north the level of the water of the lake was lowered, and finally found an outlet to the northeast. The complete retreat and disappearance of the ice-sheet gave present day conditions.

During the existence of Lake Agassiz beaches, terraces, and other evidences of shore lines were formed on its margin, and remained after the recession of the ice-sheet and the lowering of the water level. These are evident today and are important in the topography of the valley, as well as economically important as supplies of sand and gravel.

In the southern part of the area of this glacial lake, within 75 miles of its outlet at Lake Traverse, five principal beaches have been observed, and in their descending order have been named, from towns in Minnesota near which they are well exhibited, the Herman, Norcross, Tintah, Campbell and McCauleyville beaches. These shore-lines, however, when traced farther north, are found to become double or multiple, due to an elevation of the northern part as the ice-sheet retreated and its great weight was removed from the earth's crust. In the vicinity of Maple Lake, Minnesota, the Herman beach is divided into five beaches, corresponding to the single Herman beach at the southern outlet. In like manner the Norcross and Tintah beaches are each represented at the north by two, and the Campbell and McCauleyville beaches each by three distinct shore-lines, separated by slight vertical intervals. The northern part of the lake has thus no less than seventeen shore-lines, which were successively formed from the highest to the lowest during the time of the southward outflow through Lakes Traverse and Big Stone and the Minnesota river to the Mississippi.

After the lake obtained its earliest outlet to the northeast, sinking below Lake Traverse, it formed fourteen shore-lines. The first three of these pass near Blanchard, N. D., and these are denominated the Blanchard beaches. The next in descending order is the Hillsboro beach, the succeeding two are the Emerado beaches, and the next lower the Ojata beaches, named similarly from other towns in this state. The remaining six lower beaches are named from localities in Manitoba. In the same descending order they comprise the Gladstone, Burnside, Ossowa, Stonewall and Niverville beaches, the last being double. There are thus in total thirty-one separate shore-lines of this lake in the northern portion of its area; and all of them, excepting the lowest, extend south of the international boundary.

Owing to the conditions under which the field work was carried on and owing to the fact that Mr. Warren Upham did a large amount of detailed work on the shore lines of Lake Agassiz the results of which are contained in Monograph XXV of the United States Geological Survey the writers thought it unnecessary to spend much time on this portion of the work. Instead, some of the more important features and their relations to the remainder of the area were studied, and the writers have drawn freely from the above monograph in the preparation of this report.

Golden Valley. Golden Valley on the north line of sections 4 and 5, Vernon township, has an elevation of 1,185 to 1,195 feet, showing an ascent of 10 feet from east to west in its width of 2 miles. About the same transverse slope, raising the west side of the valley 10 to 15 feet above its east side, is found along its whole extent of 18 miles from the North Branch of the Forest river to the Middle and North Branches of the Park river. From the south boundary of Golden Valley northward, the width of this valley varies from two to only one mile. It is flat, and its bottom and sides consist mainly of clay free from gravel; but wells find gravel intermixed with the clay, probably till, at a depth of a few feet, and about twenty feet from the surface they sometimes encounter a waterbearing stratum of gravel, chiefly made of Cretaceous shale. The highest part of Golden Valley south of the South Branch of Park river, along the north line of sections 27, 28, 29, in Golden township, is 1,199 feet on the east to 1,211 feet on the west. Golden Valley, on the north line of section 29, Lampton

township, is 1,198 to 1,208 feet. In this northern part of the valley limited tracts of its flat area are strewn with abundant boulders up to two feet, and less frequently three or four feet, in diameter. They are probably where swells of till rose nearly to the surface of the water in this strait of Lake Agassiz, so that its fine portions were swept away by waves and currents, to be deposited elsewhere in the valley as clayey silt, leaving the masses of rock which would not be thus removed. Approaching the Middle Branch of Park river, the surface of the Golden Valley continues very smooth and flat, but it ceases to have a continuous ascent from east to west, some portions along the center being depressed a few feet, and thus allowing the formation of shallow sloughs.

The west border of the Golden Valley was the most western shore of Lake Agassiz in its highest stage, but it is only very scantily marked by deposits of beach gravel and sand, because of its sheltered position on the western and leeward side of this narrow strait. From the southeast corner of section 32, Golden township, this shore-line extends in a quite direct course a few degrees west of north through sections 32, 29, 20, 17, 8, and 5 of this township and the east edge of sections 31 and 30, Lampton township. For the next three miles, in the east edge of sections 19, 18, and 7, Lampton township, it runs nearly due north. Thence it turns to a northwesterly course through section 6 of this township, and section 31, Gardar township. In this vicinity the Golden Valley terminates.

Bushes and trees clothe the slope on the west side of the Golden Valley along its northern part, extending to the south line of Lampton township; but this ascent farther south, also the entire extent of the Golden Valley, the drift hills forming its east border, and the vast plain of the Red River Valley, are prairie, excepting that narrow belts of timber border the water courses.

Smoothly undulating till rises slowly from the west side of the southern part of the Golden Valley, but in section 30, Lampton township, rounded hills of till attain a height of about 100 feet above the valley or 1,300 feet above the sea. Thence northward a smooth slope ascends 50 to 60 feet, or in some portions only 30 or 40 feet, within the first quarter or half mile to the west, succeeded beyond by a moderately rolling surface with less ascent.

A terrace of beach sand and gravel, containing pebbles and cobbles up to six inches in diameter, extends a third of a mile from southeast to northwest, with a width of 5 to 30 rods, in the northwest quarter of section 33, Lampton township, abutting on the west flank of the rolling and hilly deposits of till which make the east border of the Golden Valley. It was formed by currents entering this strait of Lake Agassiz; it has an elevation of 1,213 to 1,195 feet, declining from north to south, and also sinking one or two feet from west to east in its width of 100 to 500 feet, being thus slightly higher along its verge than where it rests upon the adjoining hilly till.

From the north side of section 32, Eden township, Walsh county, an island of rolling and hilly morainic till above the highest level of Lake Agassiz extends, with the exception of two short gaps, twenty miles northward, varying in width from a half mile to a little more than one mile in its southern quarter and from one and one-half to two and one-half miles through the remainder of its extent. This hilly tract, commonly denominated "the mountains," forms the east border of the Golden Valley. In the north part of section 36, Vernon township, it has a depression to about 1,180 feet, which probably was a strait of the glacial lake in its highest stage, an eighth of a mile wide, and a few feet deep. Again in the center of Golden township, it is intersected by the South Branch of Park river, which has a valley a quarter to a half of a mile wide and about seventy-five feet deep. The stream in its course of one and a half miles through this belt descends about fifty feet, from 1,165 to 1,115 feet, approximately. It seems almost certain that a depression slightly lower than the Golden Valley on the west originally extended across this rolling and hilly area where it is cut by this stream; but the erosion of its valley has undermined and removed portions of adjoining hills and ridges, so that its inclosing bluffs now rise 50 to 100 feet, their highest points being about 1,225 feet above the sea, or twenty-five to thirty feet above the east edge of the Golden Valley. All these bluffs and two plateaus left in the midst of the valley are till, yellowish near the top and dark-bluish below.

The elevation of "the mountains" in their southern and narrower portion varies from 1,190 to 1,250 feet above sea level; in the south part of Golden township, 1,200 to 1,260 feet and through the north

half of this township and the south half of Lampton township, 1,200 to 1,275 feet, being highest in section 28 of the township last named, near the northern end of this hilly tract. These prominent accumulations of till, rising in the west edge of the lacustrine area, are probably referable to the ninth or Leaf Hills moraine and appear to have been formed on the western margin of the Minnesota lobe of the ice-sheet, as explained in the general consideration of the area.

The Great Northern Railway at Park River depot is 998 feet above the sea; the natural surface at the southeast corner of section 23, Golden township, on the road leading west from Park River, 1,178 feet. The crest of the upper Herman beach, crossed by this road ten rods west from the point named, it at 1,187 feet, but twenty rods southeast and northwest from the road its height is 1,192 feet. This is a typical beach ridge of sand and gravel, with pebbles up to two or three inches in diameter, mostly limestone and granite. The Cretaceous shale before mentioned is very rare in the till of "the mountains" and in the beaches formed along their east side, indicating that the east limit of this shale is the Pembina Mountains and the western ascent of the Golden Valley, and that the glacial currents by which the drift here was deposited came only from the north and northeast, with no intermixture of currents from west of north.

Lake Agassiz Beaches. The highest beach on the verge of south bluff of the South Branch of Park river, in the southeast quarter of section 23, Golden township, is 1,188 to 1,192 feet high with a basin-shaped hollow on its west side twenty feet lower, which changes southward to a depression of about five feet. The river bluff here shows the depth of beach sand and gravel to be two to ten feet, lying on till. The lower beach, a quarter of a mile farther east, extends from northwest to southeast, in the southwest quarter of section 24, and is 1,167 to 1,170 feet high.

The lower Herman beach is a massive ridge of gravel and sand, extending in a curved course convex toward the east from the northeast quarter of section 2, Golden township, through the southeast part of section 35, Lampton township, with a crest 1,160 to 1,165 feet high; through the northeast edge of section 36, and the southwest corner of section 25, it is 10 to 50 rods wide, with slightly undulating surface, and is 1,160 to 1,167 feet high; near the middle

of the east side of the southeast quarter of section 26, it is 1,165 to 1,166 feet high; and at the quarter-section stake on the north side of this section 26, it is 1,163 feet.

Near the west line of section 23, Lampton township, two Herman beaches abutt upon the east flank of the north end of "the mountains" and extend thence north-northwest two miles to the Middle Branch of Park river. The eastern one, a well-defined ridge of sand and fine gravel passes close west of the quarter-section stake between sections 15 and 10. The elevation of its crest is 1,161 to 1,166 feet, increasing in height from south to north; the descent on the east is fifteen to twenty feet in as many rods, and the depression on the west is three to eight feet deep and ten rods wide. The other beach ridge is forty or fifty rods farther west, parallel with the preceding and similar in form and material, its crest rising slightly northward, is 1,173 to 1,176 feet above sea level. Another distinct beach ridge, but of smaller size, runs in a parallel course through the east part of the southwest quarter of section 9, with its crest at 1,185 to 1,187 feet. These appear to represent together the second and third Herman beaches. The lowest Herman beach in this vicinity passes as a well-marked ridge of gravel and sand through the west part of sections 11 and 2, Lampton township, and the east part of sections 34, 27 and 22, Gardar township, having a height of 1,145 to 1,150 feet, from which there is a descent of five to ten feet on the west.

The upper Herman beach, northward from the north end of "the mountains," forms in the northwest quarter of section 21, and the west part of section 16, Lampton township, a massive broad ridge, composed of sand and gravel, with pebbles up to four or even six inches in diameter, with a crest 1,197 to 1,207 feet high, rising higher northward, where the beach deposit overlies the eastern slope of a wave-like swell of till that rises to 1,212 feet. A small beach ridge belonging to this stage is on the east edge of the southeast quarter of section 8, Lampton township, and is 1,202 to 1,207 feet above sea level. The surface in the western part of the southwest quarter of section 9, is 1,197 feet high, consisting of sand and gravel of this beach to a depth of ten feet. The summit of a smoothly rounded hillock, probably till, but having few or no boulders, in the east edge of the northeast quarter of section eight, is about 1,230 feet; train of beach gravel and sand

extending thence thirty rods southward, rises 1,217 feet above sea level with descent of fifteen or twenty feet on each side. Continuing beyond the Middle Branch of Park river, this highest beach is well developed in a broad ridge running due north through the west part of section 4, Lampton township, with its crest at 1,202 to 1,208 feet. On the east the surface falls thirty or forty feet, and more slowly beyond, while toward the west a descent of ten feet is succeeded by a flat surface of till, which rises slowly from the foot of the beach ridge to a swell at the height of 1,215 to 1,225 feet, a half mile away, forming the east boundary of the Golden Valley. This beach is of sand and gravel, with pebbles up to six inches in diameter. About half of them are limestone; nearly all of the remainder are Archean granite, gneiss and schists; scarcely one in two hundred is Cretaceous shale. Through the west edge of section 33, Gardar township, the elevation of this excellent beach is 1,202 to 1,205 feet, and in the southwest edge of section 28 and the middle of the east edge of section 29, 1,202 to 1,197 feet, decreasing in size and height northward. For a half mile through the southwest quarter of section 33, there is a slight secondary beach ridge, four to nine feet lower which lies about thirty rods east of the foregoing; its crest is at 1,198 to 1,195 feet above sea level sinking a few feet from south to north; it is divided from the higher beach by a continuous depression about three feet deep.

A very massive beach ridge, composed of sand and gravel, with pebbles and rock fragments, the largest only slightly waterworn, up to six inches in diameter, passes a few degrees west of north through the center of section 20, Gardar township, its crest in the south half of the section being at 1,208 to 1,215 feet, and in the north half 1,215 to 1,223 feet. On the east is a descent of twenty to thirty feet within twenty-five to forty rods, and on the west ten or twelve feet from the highest part of the beach within ten rods to a nearly level area of till, 1,211 feet, which sinks forty rods farther west to a long slough, about 1,205 feet high, parallel with the beach and a sixth of a mile wide. Beyond this an undulating surface of till, partly covered with bushes and small trees, rises to 1,250 or 1,275 feet within two miles, and then in massive swells to 1,450 or 1,500 feet within the next two to four miles. These are part of a plateau rising thence more slowly westward, whose boundary for the seventy-five miles to the north-northwest is the conspicuous escarpment called Pembina Mountain.

The north end of this massive beach bears on its crest an artificial embankment 100 feet long from east to west and twenty feet wide, raised two feet above the natural surface, its top being 1,225 feet above the sea. This is ten rods south from where the beach is cut to 1,210 feet by a wide gap as of some ancient watercourse. In the south edge of the southwest quarter of section 17, Gardar township, on the south bank of the North Branch of Park river about ten rods east from the ford of the "Half-breed Road," this beach has an elevation of 1,220 feet.

The North Branch of Park river at this ford is ten to fifteen feet wide and a few inches deep with elevation of 1,203 feet. Its surface at the village of Gardar a mile east, 1,175 to 1,170 feet. Lower Herman beach, passing from south to north along the west side of sections 20 and 17, Gardar township, a third of a mile west of the village, about 1,185 feet.

Sections 17, 8, and 5, Gardar township, rise from 1,190 to 1,200 feet on their east side to 1,220 and 1,225 feet on the west, including, therefore, the upper Herman shore of Lake Agassiz; but they present no considerable deposits of beach gravel and sand. A swell of till, sprinkled with very abundant boulders, nearly all Archean granite and gneiss, up to five feet in diameter, extends from south to north across the line between sections eight and five, having its crest at 1,215 feet, from which there is a steep descent of ten or twelve feet to the west.

The south branch of Cart creek, in sections 31 and 32, Thingvalla township, is bordered by a belt of timber, but it is only a small channel a few feet below the general surface, and is dry through the greater part of the year. Its alluvial gravel, like that of the middle and north branches of Park river, is mostly Cretaceous shale, derived from the gorges eroded in this rock at the sources of these streams in the Pembina Mountain.

Along the western border of Lake Agassiz here and northward into Manitoba extends a prominent wooded bluff, the escarpment of a treeless plateau which from its crest stretches with slow ascent westward. This escarpment commonly called the Pembina Mountain, is a very marked feature in the topography for about seventy-five miles. It is caused by the outcrop, mostly overspread by glacial drift, of a continuous belt of nearly horizontal Cretaceous shale several hundred feet thick. Its course coincides nearly with

the west line of Gardar and Thingvalla townships. Thence it continues in an almost straight course, a few degrees west of north, to the international boundary, beyond which it runs north-northwest nearly fifty miles to the vicinity of Treherne. The base of the ascent is about 1,225 feet above sea level, and its crest approximately 1,500 feet, northward to the Pembina river, beyond which the base sinks to 1,150 and 1,100 feet and the crest to 1,400 and 1,300 feet. The width occupied by the slope varies from a quarter to a half of a mile.

The natural surface at the quarter-section stake on the north side of section 32, Thingvalla township, is 1,178 feet above the sea. Sections 32, 29 and 20 of this township are mostly till, smoothed by this glacial lake, the depressions having been filled by leveling down the higher portions, where many boulders partially embedded testify to considerable erosion. A broad beach of sand and fine gravel three to five feet high extends from south to north through the center of section 29, its crest being at 1,180 to 1,182 feet high. This is the third in the series of four Herman beaches. The higher beaches are probably also recognizable one to one and one-half miles farther west near the base of the Pembina escarpment or "second mountain," which is 1,220 to 1,230 feet above the sea; but it is impracticable to trace their course and determine their exact elevation, because woods reach from the base of this escarpment a half mile east where these beaches belong.

The fourth Herman beach is a broad, low swell of sand and gravel extending north-northwesterly through the east half of section 20, Thingvalla township, with elevation of 1,166 to 1,172 feet; through sections 17 and 8, an eighth to a quarter of a mile wide, and 1,161 to 1,173 feet high, having in some places a depth of at least 10 feet, as shown by wells. On the north line of section 20, and again in the north part of section 17, it is intersected by branches of Cart creek, which occupy valleys about 40 feet deep and an eighth to a quarter of a mile wide. Brush and scattered trees grow in these valleys and on the area between them. Toward the east a descent of 30 to 40 feet is made within the first half mile; westward there is only a slight ascent, to about 1,200 feet in one mile; then a more considerable slope, covered with woods, rises 20 to 40 feet to the base of the "second mountain," on or near the township line.

In the west part of section 8, and again near the northeast corner of section 6, Thingvalla township, this beach is intersected by the head streams of Willow creek, in valleys about 35 feet deep. On the north line of sections 5 and 6 of this township the third and fourth Herman beaches are merged in an undulating tract of gravel and sand a half mile wide, which rises from 1,160 feet on the east to 1,184 feet on the west. A well on the west part of this belt found the beach deposit 6 feet thick, underlain by till, which forms the slightly ascending surface next west.

The base of the second Pembina mountain, in the east half of section 31, T. 161, R. 56, varies from 1,235 feet at the south to 1,220 feet northward, coinciding nearly with the upper Herman shore of Lake Agassiz. A well twenty-four feet deep was sunk near the center of section 30, situated about fifty feet above the Tongue river, a few rods back from the verge of its north bluff, and was in soil two feet; gravel, nearly all Cretaceous shale, eight feet; underlain by gravel, nearly all granite and gneiss, with scarcely an intermixture of shale, containing pebbles and cobbles up to four inches in diameter, fourteen feet, yielding a permanent supply of water. This well is close to the base of the "mountain," at an elevation of about 1,230 feet. Its bed of granite gravel appears to be the upper beach, the overlying shale gravel being a delta deposit brought by the Tongue river.

The surface in the northeast corner of the southwest quarter of section 32, T. 161, R. 56, is 1,192 feet. The well here, 14 feet deep, is wholly stratified gravel and sand, being a beach deposit of the second and third stages in the Herman series. The third beach lies about an eighth of a mile east and is a broad ridge of sand and fine gravel, a few feet above the land on its west side, with crest, 1,187 feet.

The fourth and lowest Herman beach, of similar form with the last, but larger, runs a few degrees west of north, through the west edge of section 33, 1,175 feet, with depression of 1 to 5 feet on its west side, and descent of 25 feet within 30 or 40 rods east.

The Tongue river, at a bridge near the center of the south half of section 28, T. 161, R. 56, about 1,110 feet above sea level; bottom land, 10 feet higher; top of the bluffs, about 1,150 feet. Gavins creek in the south half of section 20, is about 1,140 feet high; valley, 40 feet deep and a sixth of a mile wide.

The lowest Herman beach forms a massive ridge of sand and fine gravel in the northeast quarter of section 29, and the east part of sections 20 and 17, T. 161, R. 56, with its crest at 1,175 to 1,180 feet.

Pembina Delta—The largest tributary of the Red river in North Dakota is the Pembina river, which has cut a valley about 400 feet deep and a mile wide in the plateau of the "second" Pembina Mountain. During the recession of the ice-sheet this stream was much larger than now, being for a time the outlet of glacial lakes in the basins of the Souris and Saskatchewan rivers.¹ The delta deposited in the margin of Lake Agassiz by the Pembina river, swollen by a great affluent from the melting ice fields at the northwest, beyond the present limits of its basin, extends about sixteen miles from south to north, and has an average width of about five miles with a maximum thickness exceeding 200 feet. Its mean thickness is probably not less than 150 feet, giving it for its volume about two and one-third cubic miles, spread upon an area of 80 square miles. Four-fifths of this delta lies south of the Pembina river reaching nearly to the Tongue river.

Its elevation in the northwest part of section 17, T. 161, R. 56, is 1,200 feet; thence northward it rises slowly in two miles to 1,225 feet in the east part of section 6; and in sections 30 and 31, T. 162, R. 56, it varies from 1,220 to 1,227 feet. From this crest of the southern part of the delta it slopes slowly east and northeast to 1,080 and 1,090 feet at its eastern border, in sections 25, 24 and 13, which coincides nearly with the east line of T. 162, R. 56. Deep valleys, with frequent tributary ravines, have been eroded in it by several small streams. Westward the delta reaches to the base of the second Pembina Mountain, the belt, a half to one mile wide, next beyond the crest, only about 5 feet lower, being a very flat, beautiful prairie, which rises slowly, like the crest, from south to north. The elevation of this belt in section 18, T. 161, R. 56, is 1,190 to 1,195 feet, and in the middle of the east edge of section 36, T. 162, R. 57, 1,221 feet. Farther west there is an ascent of about 1,240 feet at the base of the "second mountain." Wells on this area penetrate only beds of sand and gravel easy to dig and needing to be curbed to prevent caving. A large proportion, probably half, of the gravel is formed of Cretaceous shale. Water is obtained at depths varying from 25 to 60 feet.

¹Mon. XXV. U. S. Geol. Survey, pp. 267-274; Geol. and Nat. Hist. Survey of Minn., Ninth Ann. Report, 1880, p. 342; Hinds Report of the Assiniboine and Saskatchewan Exploring Expedition, 1895, pp. 118-168.

The part of the Pembina delta thus far described is divided from its central and higher part, which is shown in Plate XXIII, by a depression about a mile wide, through which a portion or whole of the river flowed during much of the time that this delta was being formed. In the southwest corner of section 18, T. 162, R. 56, this depression is 1,205 feet above the sea, being 20 feet lower than the area on the south. It extends eastward with a slow descent, and rises westward to 1,215 feet, just east of the Little Pembina river, in section 15, T. 162, R. 57. This stream flows through the escarpment of the "second mountain," to its junction with the Pembina river, thus leaving the depression just described, which would seem to be its more natural course and taking in its stead a channel that is eroded through a portion of the delta 50 feet higher.

The most elevated point of this delta is about 1,270 feet above the sea, near the northwest corner of section 11, T. 162, R. 57, east of the Little Pembina and south of the Pembina river, and is nearly 300 feet above the junction of these streams, one and one-half miles distant toward the northwest. Section 12 of this township and the west part of section 7, T. 162, R. 56, slope from 1,225 feet on the south, to 1,215 feet on the north; their southern part is the highest land crossed between the depression before mentioned and the Pembina river by the line dividing these townships. The level of Lake Agassiz in its highest stage here was 1,220 or 1,225 feet above the sea, being 50 feet below the top of the Pembina delta, as is shown by the beach line of this level, 1,226 feet, in the central part of section 7, where an eastward descent begins. This is the east verge of the nearly flat area of the delta in sections 12 and 7. Like all of this delta deposit the material here is sand and gravel, covered by a fertile soil. A small proportion of the pebbles of this gravel is limestone; a large part is Cretaceous shale, but more was derived from Archean formations of granite and gneiss.

The second Herman beach, a ridge of the usual form, is crossed by the road near the east side of the northeast quarter of section 7, T. 162, R. 56, descending from 1,212 feet to about 1,200 feet in a distance of a third or a half of a mile from north to south.

A well 110 feet deep, in the northwest quarter of section 8, T. 162, R. 56, at an elevation of 1,189 feet, is in stratified sand and gravel, with pebbles up to six inches in diameter, fully half Cretaceous shale. Water comes in coarse sand at the bottom, filling the low-

est two feet. Another well of the same description, but 137 feet deep, is a mile farther east, in the southwest quarter of section 4, 1,192 feet above the sea.

On the road from Olga to Walhalla the crest of the east margin of this delta is crossed in the north part of section 33, Walhalla township, about two miles southeast from the village of this name. Its elevation is 1,190 to 1,196 feet above the sea. This is a beach accumulation, belonging to the third Herman stage. Toward the west and southwest the undulating delta plateau is 10 to 30 feet lower for a width of one to one and one-half miles, averaging about 1,175 feet. Northeast from the crest of this road a short descent is made to a prairie terrace, 30 to 60 rods wide, varying in elevation from 1,182 to 1,169 feet, but mainly within 2 feet above or below 1,175 feet. In general the edge of this terrace is its lowest portion. Thence a very steep descent of 169 feet is made on the road from 1,173 to 1,004 feet, this being the conspicuous wooded escarpment called the "first mountain." It is the eroded front of the great Pembina delta, the eastern part of which originally descending more moderately, has been swept away by the waves and shore currents of the lake during its Norcross, Tintah, Campbell and McCauleyville stages. From section 33 the "first mountain" extends southeast to sections 13 and 24, T. 162, R. 56, and northwest across the Pembina, passing just southwest of Walhalla and onward to sections 10 and 3, T. 163, R. 57. Its highest part is intersected by the Pembina river, above which it rises on each side in bluffs of gravel and sand, 200 to 250 feet high, with their crest one-half mile to a mile apart. From this upper portion the delta slopes down gradually toward the southeast and toward the northeast and north, extending only two to four miles north of the Pembina.

The surface at Walhalla is 968 to 994 feet; Pembina river at the bridge, a third of a mile east of Walhalla, at low and high water, is 934 to 943 feet.

The highest part of the Pembina delta north of the Pembina river in sections 25 and 26, T. 163, R. 57, is 1,210 to 1,230 feet, rising slowly from east to west; in the west half of section 26 and the east edge of section 27 it is depressed to 1,225 and 1,220 feet; but beyond this it rises to 1,235 and 1,240 feet, next to the foot of the "second mountain."

The surface at the quarter-section stake on the north side of section 26, T. 163, R. 57, is 1,191 feet. The crest of the third Herman beach five rods south of the stake, is 1,197 feet above sea level, from which there is a descent in five rods to 1,192 feet and in 15 rods to 1,180 feet. This beach curves thence to the northwest and north, and in the opposite direction runs east-southeast two miles to near the center of section 30, Walhalla township, where its elevation is approximately 1,192 feet. Other shore lines of the Herman group were not noticed north of the Pembina river.

From the erosion of this first Pembina Mountain, by the glacial Lake Agassiz during its recession, large quantities of gravel and sand were swept southward, notably during the Campbell stages of the lake, when they were deposited in a very massive curving beach ridge that crosses the Tongue river in the west part of T. 161, R. 55, about seven miles west of Cavalier.

Through Eden township, and the next 5 miles northward to the vicinity of Edinburgh, the Norcross shores on the eastern side of "The Mountains" lie mostly within a half mile to one mile from the highest Herman shore. Upon this somewhat steep slope, intersected by numerous ravines, neither the Herman shores nor the Norcross shores are so distinctly traceable as usual, either by beach deposits or by lines of erosion.

From the northern end of "The Mountains," near Edinburgh, the Norcross shore lines run north-northwestward, passing about two miles east of Gardar, less than a mile west of the village of Mountain, and through the eastern half of section 33, T. 161, R. 56. At the locality last named the upper Norcross shore lies about a third of a mile east of the lowest Herman beach, and is marked by a ridge of gravel and sand 10 to 20 rods wide, with a depression of one to four feet on its west side and a descent of about six feet in a few rods to the east. Its crest has an elevation of 1,143 to 1,145 feet, being thirty feet lower than the adjacent Herman ridge.

The outer border of the plateau of the Pembina delta, forming the "first Pembina Mountain," was the Norcross shore of Lake Agassiz. After the Herman stage of this lake all its lower levels with southward outflow washed the front of the Pembina delta, carrying away much of this deposit southward and eastward, and producing the steep escarpment, mostly 100 to 175 feet high, by which it is bounded on the east.

On the more gradually sloping northern edge of this delta, two to four miles west of Walhalla, a beach formed during the lower Norcross stage passes from east-southeast to west-northwest. In the north half of section 23, T. 163, R. 57, where its crest has an elevation of 1,135 to 1,120 feet, it is a broad, low ridge, chiefly of sand, with fine gravel, containing pebbles up to one or two inches in diameter. Most of the gravel is derived from the Cretaceous shale of the Pembina Mountain, but a part is of limestone and crystalline Archean rocks. A depression of five or six feet, fifteen to twenty rods wide, lies on the southern side of the beach, away from the lake, and its northern side falls off into the lacustrine area with a gentle slope.

Two miles farther northwest the Norcross shore-lines, with the entire Herman series, leaving the Pembina delta, sweep into the great Cretaceous escarpment of the second Pembina Mountain with which they coincide for several miles northward, crossing the international boundary.

From Eden township northward to the Pembina delta the courses of the Tintah shores, though not exactly traced, are known very nearly from the rate of eastward descent of the land and from the mapped course of the next succeeding Campbell beach. At one locality a Tintah beach ridge was noted, near the middle of the line between sections 19 and 18, Kensington township, about two miles northward from the town of Park River; but for the next two miles or more northward there is a rather irregularly rolling surface, with no definite beach observable.

The Tintah shores are only a short distance below those of the Norcross stages on the flanks of the Pembina delta and on the lower part of the Pembina Mountain escarpment for several miles thence northward.

Beyond Conway, for a distance of about thirty-five miles, the Campbell shore-line, passing through the west edge of the town of Park River and close by the east side of the village of Mountain, is almost uninterruptedly an eroded escarpment of till, with eastward descent of twenty to thirty feet, or rarely forty feet, within an eighth of a mile or often a less distance. At Park River the Campbell escarpment falls rather abruptly from 1,035 to 1,015 feet above the sea; and thence a gentle slope of till sinks about fifteen feet lower in a half mile east to the McCauleyville beach and the

railroad. In the northwest corner of Dundee township, ten miles north of Park River, the escarpment falls from 1,045 to 1,015 feet, being steep in the upper half, which consists of till; then it descends more slowly a few feet, also in till, with frequent boulders; and its lower third is a somewhat steep slope of beach sand, and coarse gravel.

From the foot of the escarpment a smoothed surface of till slopes gradually eastward, having an estimated descent of 100 feet within three miles. In section 2, Gardar township, the crest of the escarpment, at 1,045 feet, bears a slight ridge of beach gravel and sand, two to three feet above the surface of till on the west; but the face of the escarpment, here falling twenty-five feet within thirty rods to the east, is till, enclosing plentiful boulders of granite and gneiss. A few miles farther north, at a distance of about one mile south of the village of Mountain the steep slope falls from 1,040 to 1,000 feet, and is covered with a beach deposit of gravel and sand from 1,030 to 1,020 feet, while the higher portion and a broader belt forming its foot, like the lower land extending eastward, are till. At Mountain this shore descends thirty feet, from 1,045 to 1,015 feet, within a distance of about twenty-five rods. It is wholly till, with no associated beach formation, as also are the more gentle slopes on both sides, sinking toward the east and rising westward. During all the Campbell stages of Lake Agassiz erosion was in progress upon this long escarpment; but in some localities the action of the waves in cutting away and removing till was temporarily changed, alternating with accumulation of shore deposits of wave-brought gravel and sand.

Erosion of the base of the "first Pembina Mountain"—that is, the front of the Pembina delta, along a distance of six miles to the southeast from Walhalla—supplied an extraordinary, massive Campbell beach or embankment, verging from a quarter of a mile to nearly one mile in width, which extends eight or nine miles in a curving course, convex to the southeast through sections 5, 8, 17, 20, 29 and 30, T. 161, R. 35, and the south half of section 25, the southwest quarter of section 26, and the west half of section 35, T. 161, R. 56. This broad belt consists of gravel and sand, fifteen to forty feet or more in depth, which were carried southward by the shore currents of Lake Agassiz in its Campbell stages, the greater portion being transported six to twelve or fifteen miles.

The crest or somewhat plateau-like top of the embankment in its course of six miles south of the Tongue river has an elevation of 1,020 to 1,030 feet above the sea. In its narrower part north of the river, its crest ranges from 1,028 to 1,033 feet along the first mile from the river; 1,030 to 1,035 feet along the next mile; and 1,035 to 1,045 feet, averaging 1,040 feet, in its third and most northern mile; passing through the southwest edge of section 29, T. 162, R. 55, where it becomes an ordinary beach ridge only twenty to thirty rods wide, with descent of fifteen feet to the east and five feet to the west. The process of accumulation of the extensive embankment was by transportation of its material along the shore that is marked by the beach ridge, and by building it thence out into the lake in this long hook bent to the west, which grew gradually in length and in height until it rose to the lake level, its growth afterward being by addition to its width. From its eastern verge a slope of the same gravel and sand falls thirty to forty feet in a third or half a mile, to a south to north belt of dunes and sand ridges, ten to fifteen feet high, which appear to represent the McCauleyville beaches. West of this embankment a basin fifteen to forty feet below it, mostly consisting of fertile land, well drained by the Tongue river, extends six miles from south to north, with a maximum width of about three miles, lying between the embankment and the southeastern border of the Pembina delta, which was the lake shore during the Norcross and Tintah stages. The prevailing course of the coastal currents of Lake Agassiz, and of the transportation of its beach material here and elsewhere, on both its western and eastern sides, was from north to south, as now on Lake Michigan, due then and now to the prevailing directions of the winds, and especially gales and severe storms, when the broader and higher portions of the beaches were chiefly amassed.

At Walhalla and northwestward the Campbell shore-lines run along the base of the escarpment of the Pembina delta, where its steep descent is succeeded by a more gentle slope. The principal lower Campbell shore, from one-half mile west of Walhalla to two miles northwest, is in part a well-developed beach ridge, with crest 1,030 to 1,035 feet above the sea, but is mostly a terrace eroded in the delta deposit, falling from 1,040 to 1,020 feet approximately. In the northeast part of section 14, T. 163, R. 57, about three miles northwest of Walhalla, the upper Campbell shores form such a

terrace, which falls from 1,075 to 1,035 feet; while a more moderate slope of sand and fine gravel below, to 1,025 feet at the road running from Walhalla, probably represents the lower Campbell stage.

Three miles farther northwest and about one mile south of the international boundary a terrace of gravel and sand in the west part of section 34, T. 164, R. 57, marks the Campbell beach of the lake. The front of the terrace rises steeply from 1,015 to 1,035 feet above the sea, and its top has a further gentle ascent of ten to fifteen feet in its width of about fifty rods to where it abutts on the base of the lowest escarpment of the Pembina Mountain, which rises from 1,050 to 1,100 feet. From the top of this escarpment a terrace or plateau of till and underlying Cretaceous shale extends across a width of three-fourths of a mile west to the principal Pembina escarpment. The upper Campbell level probably passed along the top of the sand and gravel terrace, near the elevation of 1,045 feet; the second level of the series was near the verge of this terrace, approximately 1,035 feet; and the third and lowest stage coincided with the lowest third of its steep front.

Through a distance of about twenty-five miles from Park River to the Pembina delta, the McCauleyville shore, probably marked throughout by a deposit of gravel and sand, lies about a half mile east of the Campbell escarpment.

A belt of low dunes in sections 28, 21, and 16, T. 161, R. 55, running along the eastern base of the great Campbell embankment that was built out to the south from the front of the Pembina delta, probably records the McCauleyville stages, approximately at 1,000 to 980 feet above sea level. North of the Tongue river the McCauleyville shores lie a third to a half of a mile east of the Campbell embankment and beach ridge for a distance of five miles. Thence through the next six miles, extending northwest to the Pembina river and Walhalla, they run along the base of the first Pembina Mountain, which is the very steep ascent, 100 to 175 feet high, of the eroded east border of the Pembina delta plateau.

The road from Olga to Walhalla, coming down from this plateau about a mile southeast of the Pembina river, crosses at its foot a terrace of sand and gravel, thirty to fifty rods wide, having an elevation of 1,000 to 1,009 feet above the sea, which was formed during the upper McCauleyville stage. The highest part of the terrace is at the point where it rests against the "mountain," and its surface

descends a few feet to its northeastern verge. There is next a somewhat rapid slope to 985 feet at the bottom of a depression about fifteen rods wide, beyond which the road passes over the beautifully developed lower McCauleyville beach. This ridge is twenty to thirty rods wide, with smoothly rounded top at 990 to 993 feet, very level along a visible distance of a third of a mile or more of its course from southeast to northwest. Its lakeward northeastern slope falls about twenty feet within twenty-five rods, and from its base a slower descent continues eastward.

All the land of this vicinity, including the plateau and front of the delta, the terrace and beach ridge, the intervening hollow, and the flat country on the east, consists of gravel, sand and fine silt, belonging to the delta as it was originally deposited, or as it has been worked over by the lake waves during later stages. Indeed, proceeding eastward thirty miles to the Red river at Pembina, St. Vincent and Emerson, one crosses only the fine silt which was of like origin with the delta but was carried into the lake, or the similar alluvial beds that have been laid down from floods of the Pembina, Tongue and Red rivers since Lake Agassiz was drained away.

Between Walhalla and the international boundary the McCauleyville shore lines lie on the western margin of the flat expanse that stretches from the Red river to the Pembina Mountain, being a quarter of a mile east of the first conspicuous westward ascent. In section 2, T. 163, R. 57, about two miles south of the boundary, they form a tract of sand and fine gravel, forty to fifty rods wide, drier than the adjoining surface on the west and east, passing by Elm Point, the eastern limit of the groves, at that place consisting mostly of large white elms, which extend outward from the wooded Pembina escarpment along springy watercourses scarcely depressed below the general surface. The elevation of this gravelly tract is 997 to 1,002 feet. It is not a distinct ridge or even swell, and is recognizable chiefly by the contrast of its comparative dryness, which has caused it to be selected as the site of farmhouses. The adjoining moist and springy land on the east descends fifteen or twenty feet in the first third of a mile, but thence the surface sinks very slowly to the axial lowest part of the lake basin in this latitude at the Red river, its gradients in this distance being gradually diminished from fifteen feet to only two or three feet per mile.

In the portion of the Red River Valley under consideration the Blanchard shore lines lie to the east and close to the McCauleyville beach. They continue close together and nearly parallel but this part of the Blanchard shore has not been followed with leveling.

Although three pauses in the crustal uplift are shown near Hillsboro, on the beach deposits of the same name, yet those stages seem to be united elsewhere. This shore line has a general northwest and north-northwest course, excepting that it deviates to a north-northeastward course for fifteen miles, between the North Branch of Park river and Tongue river, turning thus aside to pass by the Pembina delta. Although the course of the Hillsboro beach is mapped approximately, yet its height is known by leveling in only one place, near the centre of section 15, Walhalla township, about two and one-half miles northeast of the town of Walhalla, where the top of the beach is 940 feet above the sea, rising fifteen feet above its base twenty rods distant to the east and bordered by a depression of two to five feet on the west.

In the southern part of Pembina county the Emerado shore curves to a north-northeast course, passing by Crystal to Willow creek, and thence runs nearly north, crossing the Tongue river about a mile west of Cavalier. Along a distance of six miles north from Willow creek a low and broad secondary beach ridge, or more likely in part an offshore sand deposit that was formed a few feet below the lake's surface, has an elevation of 890 to 895 feet, with slopes sinking a few feet below this on each side. The adjoining surface is lacustrine silt, deposited in front of the Pembina delta, and the ridge is fine sand which has been somewhat gullied and hummocked by the wind.

Between the Tongue and Pembina rivers and onward to the international boundary this beach takes a northwestward course. Turning to that direction about two miles northwest of Cavalier, it thence runs nearly straight ten miles to St. Joseph, being through the greater part of the distance a typical beach ridge of sand, with scanty layers of very fine gravel. Its crest is mainly 892 to 898 feet above the sea, having a gradual ascent from south to north; but as it approaches St. Joseph and the Pembina river its last two miles rise 900 and even 905 feet above sea level. The slopes fall commonly five to ten feet northeastward and two to nine feet southwestward. The depth of the beach deposit is the same as

the fall of its eastern slope, with hard and dark stratified clay beneath. In section 2, and again in section 13, T. 162, R. 55, lying two to five miles southeast of St. Joseph, this beach widens into sandy tracts, each of which has a width of a quarter of a mile or more and is slightly raised, like the typical narrower ridge, above the adjacent surface of clayey lacustrine and alluvial silt. About a mile north of the Pembina river the Emerado level of Lake Agassiz formed a low escarpment of erosion, which passes north-northwest-erly by the northeast corner of section 17, T. 163, R. 55. Within forty rods or less from west to east it descends about ten feet, from 905 to 895 feet above the sea, approximately.

In that part of the Red River Valley under consideration the Ojata beaches are found as shown approximately mapped. They are in general, disconnected accumulations of sand and gravel, whose height above sea is about 880 feet, and rise from two to ten feet above the surface to the east.

In the area under consideration, as shown on the map, the Gladstone shore lies about four miles west of Grafton, two to three miles west of Auburn, St. Thomas and Glasston, about four miles west of Hamilton and Bathgate, and five miles west of Neche. The portions examined by Warren Upham, in Grand Forks county, are marked by slight erosion in the lacustrine and alluvial silt.

The course of the Burnside shore is known approximately and has been drawn provisionally on the map, Plate XXVIII, in accordance with the elevations ascertained by railway surveys, but no part of it has been observed to be clearly traceable by either a continuous beach ridge or an eroded escarpment. It lies on the wide, flat tract of silt which adjoins the Red river, a surface most unfavorable for the preservation of definite shore lines.

Lake Agassiz at the time of the Ossawa beach extended into the United States nearly sixty miles, but the only part of this shore which has been recognized and examined south of the international boundary is a few miles in Pembina county. In sections 21, 16 and 17, T. 162, R. 52, close south of the Tongue river, at a distance of four miles northeast from Hamilton, two or three parallel low, beach-like ridges were observed, elevated two to four feet above the intervening hollows and general surface, their height being between 815 and 820 feet above the sea. They run from southeast to northwest, and their continuation north of this river was

noted at the same height four to six miles northwestward in sections 36 and 25, Neche, about two and one half miles east-northeast from Bathgate. Both the ridges and the adjoining surface are fine silt.

Lake Agassiz, at the time of the Stonewall beach, probably extended on the flat Red River Valley to a distance of about twenty-five miles south of the international boundary, being some fifteen feet deep at Emerson, St. Vincent and Pembina, while over the site of Winnipeg its depth was about sixty feet. A somewhat ridged contour upon the otherwise very flat surface of fine alluvial silt was noted six to seven miles east of Hamilton and Bathgate. The wave-like and almost beach-like undulations, rising two to four feet above the depressions which separates them and above the general level, runs north-northwesterly through the east part of section 11 and the central part of section 2, T. 162, R. 52; close southeast of the Tongue river. Similar contour was also noticed in the continuation of this course within a few miles northward between the Tongue and Pembina rivers. The height of this belt is about 805 feet above the sea.

The southern end of Lake Agassiz in the Niverville stage was near Morris, Manitoba and its level was fifteen to twenty feet above the surface where the city of Winnipeg is built.

Pembina Mountains. A very remarkable series of highlands, forming the eastern limit of the elevated plain of the northern part of North Dakota and of western Manitoba and the Saskatchewan region, extends in a north-northwest course 400 miles, from the Pembina Mountains to the Pasquia Hills. Along much of this distance, a steep, mountain-like escarpment, which was the west shore of Lake Agassiz, rises 500 to 1,000 feet above the bed of that lake, now the low plain bordering the Red river and the great lakes of Manitoba. Topographically, this line of conspicuous highlands is allied with the Coteau des Prairies by their forming together that western ascent from the broad, continuous valley plain, which in its southeast part passes from the Red River Valley to the lowlands of the basin of the Minnesota river. Both the Coteau des Prairies and the Manitoba escarpment consist, beneath their drift covering, of nearly horizontal Cretaceous shales, whose continuation has been removed by erosion on both sides of the Coteau, but only east of the escarpment.

The southern end of the Pembina Mountain, where it is reduced to rounded hills, about 100 feet above the lowlands at their east base and 1,300 feet above the sea, is in section 30, T. 158, R. 56, between the south and middle branches of Park river. Thence for the next five miles northward this ascent is merely a slope that rises fifty or sixty feet, or in some portions only thirty or forty feet, within a quarter of a mile from east to west, succeeded beyond by a moderately rolling surface with slower ascent westward. Along the west line of townships 159 and 160 of range 56 this highland rises gradually in its course from south to north, attaining an elevation about 1,500 feet above the sea; and it holds this height quite uniformly northward to the Pembina river, in the south part of township 163, R. 57, about five miles south of the international boundary. It is a prominent wooded bluff, some 300 feet high, extending in a very direct course from south to north or a few degrees west of north. From its southern end to the Pembina river the base of this escarpment is 1,200 to 1,225 feet above sea level. The width occupied by its slope varies from a half mile to two or three miles, and from its crest a treeless plateau, having a moderately rolling surface, stretches with slow ascent westward. North of the Pembina river its crest sinks to about 1,400 feet, and its base to about 1,025 feet at the international boundary.

Where the Pembina river cuts through this escarpment, entering the area of Lake Agassiz, the eroded eastern front of its delta deposit forms another conspicuous bluff, about 200 feet high, falling in a steep, wooded slope from 1,175 to 975 feet, approximately, above the sea level. The delta bluff, called the "First Pembina Mountain," is composed of sand and gravel, and lies about five miles east of this more prolonged line of highland, which is known in that vicinity as the "Second Pembina Mountain." The latter, throughout its entire extent both in North Dakota and Manitoba, is caused by the outcrop of a continuous belt of almost level Cretaceous strata, mostly overspread by glacial drift. (See Plate XX.)

The ascent of this highland on the international boundary, where it occupies a width of about one and a half miles, is described by Dr. G. M. Dawson as follows:

"The eastern front of the Pembina escarpment is very distinctly terraced, and the summit of the plateau, even at its eastern edge, thickly covered with drift. The first or lowest terrace, which is

about one-third from the prairie level toward the top of the escarpment, does not seem to preserve exactly the same altitude. On the boundary line its height above the general prairie level was found to be about ninety feet, a second terrace 260 feet, and that of the third level, or summit of the plateau, about 360 feet. The surface of the first terrace, which is here wide, is strewn with boulders, as is also that of the second terrace and plateau above. These are chiefly of Laurentian gneiss and granite, but a few smaller ones of limestone occur. The banks of ravines cutting the top of the plateau and draining westward into the Pembina river show in some places a great thickness of light colored, yellowish, marly drift, with few boulders imbedded in it."

The topographic region of the Pembina Mountains is bounded by the escarpment on the east and on the west by the west line of range 57 as far north as the south line of township 162, and thence north by the west line of range 58 to the boundary. This northwest extension of the region is due to the deep valleys of the Little Pembina and Pembina rivers.

All of the streams in this region have cut deep valleys from 200 to 500 feet deep, which has given rise to the mountainous topography. Most of the stream valleys dwindle down to mere depressions within a few miles west of the escarpment. In the case of the Little Pembina, the valley is deep as far west as the west line of range 58, while the valley of the Pembina river is deep and precipitous far to the northwest in Manitoba. (See Plate XXI.)

In section 6, Fremont township, there is a peculiar hillock known as "Heart Mound" and to the northwest about one and a half miles, there are a series of similar mounds known as the "Black Hills." These rise above the general level of the country from fifty to 100 feet. They are formed of Pierre shale, and are remnants left by erosion. (See Plate XXIII, Fig.2.)

Stretching westward from the Pembina Mountains, lies a comparatively flat plain with slow westward ascent, and gently undulating surface. It includes the whole of Cavalier county and is formed by the westward extension of the flat lying Cretaceous strata of the Pembina Mountains covered by glacial drift of variable thickness. The relief of this region, although greater than that of the Red River Valley, is, however, quite small, and is an example of high rolling prairie. The swells of this prairie have their axes



Fig. 1. Deep valley of Little North river near its junction with Pembina river. Shows Niobrara outcrops. Deep rugged valleys are characteristic of all streams near their emergence from the escarpment.



Fig. 2. Valley of the Little Pembina river, cut in Pierre shale, north of Stilwell. Shows the manner in which the valleys flatten out and merge into the rolling prairie west of the escarpment.



as a rule running in either a north-south or an east-west direction. The swells are usually about ten feet above the intervening depressions and rarely exceed twenty-five feet.

DRAINAGE.

The Red River Valley is well supplied with streams, but is imperfectly drained, due both to the lack of relief of its surface and also to the character of its soil. The main drainage line of the region is the Red River of the North which forms the eastern boundary of North Dakota. Its clay banks are of moderate height, from twenty to forty feet, and usually rise gradually on one side and with a more precipitous slope on the other. The steep banks are on the outer side of the bends of the river. There is little or no bottom land. The maximum variability in the height of the river is a little less than forty feet.

The drainage of the region is carried to the Red river by two main tributaries, the Park river on the south and the Pembina river on the north. The three branches of the Park river, are known as the South, Middle and North branches. These unite to form the main stream about three miles northwest of Grafton. The South Branch of Park river, rising in southeastern Cavalier county, flows in a southeasterly direction to the west line of range 56, and then flowing in an easterly direction to the main stream drains a belt of country about four miles wide lying to the north of it, and a belt about six miles wide lying to the south. The Middle Branch of Park river rises in southeastern Cavalier county, just east of the South Branch. It flows in a generally easterly direction to the west line of range 54, and thence southeast to its junction with the main stream. It drains a belt of country about three miles wide on either side, except on the northern side of the point of its change of direction to southeast, where it lies close to the North Branch. The North Branch rises in Cavalier county between Milton and Osnabrock and flows in a general southeasterly direction to its junction with the main stream. It drains a strip of country about three miles wide on either side. Cart creek is the main tributary of the North Branch of Park river and joins it in the southeast quarter of section 3, Glenwood township. Cart creek is formed by the junction of many small streams rising just west of the Pembina escarpment and nearly all joining the main stream west of the east boundary of Crystal township. Cart creek

drains a fan-shaped area about fifteen miles wide to the west, and three miles wide along the main stream. All of the smaller streams of the foregoing are dry or nearly so in the summer months.

In the Red River Valley the area lying between the Park and the Tongue and Pembina rivers, and especially east of the Neche line of the Great Northern Railway, is imperfectly drained. There are many depressions in the surface of the valley which are known as sloughs and contain much water in the spring and fall but are dry in the summer. A very accurate leveling of this section has been made by the state in cooperation with the United States Department of Agriculture, and much drainage work and ditching is now in process of construction in this area. Many of these sloughs contain alkaline or salt waters.

The Tongue river is the principal tributary of the Pembina river in the Red River Valley. Rising about eight miles west of the escarpment and with its branches from the Pembina delta, it flows in a general northeast course to Bathgate and then in an irregular east and north direction to its union with the Pembina in Pembina township. It drains an area of about four miles wide to the south and about eight miles wide to the north, and contains water the year round.

The Pembina river after leaving the Pembina delta at Walhalla flows in a general northeast direction to Neche, and thence east by a little south to its junction with the Red river at Pembina. It carries much water the year round, and is the most important stream of the area. It drains a strip of country about five miles wide on either side. Its channel is only twenty to forty feet deep.

In the Red River Valley all of the streams have banks of lacustrine soil and clay, and their depth of channel varies from five to forty feet, with the exception of the Red river, whose channel is much deeper, some eighty feet.

In the Pembina Mountain region the streams have cut deep channels through the drift and underlying Cretaceous strata. At their point of emergence from the escarpment, the valleys of these streams vary from 200 to 450 feet in depth. In the majority of cases, that of the smaller streams, the channels change to mere depressions in the surface from three to six miles west of the escarpment. Notable exceptions to this are the valleys of the South Park, North Park, Tongue, Little Pembina and Pembina rivers. In the case



Fig. 1. Wide valley of the Pembina river in the Pembina delta at Walhalla. Part of an abandoned oxbow lake in the foreground. The delta is composed of silt at this point.



Fig. 2. Wide, deep valley of Pembina river in section 24, T. 163, R. 58. Shows well developed ox-bow bend of the river. In the middle distance, at the right of the illustration, the Little North river enters from the north.



Fig. 1. View looking southwest from bluff in northeast quarter of section 34, T. 163, R. 57. In the middle distance at the right is the Pembina river, which flows in front of the wooded bank in the foreground. In the middle distance is the Little Pembina river, which joins the Pembina in the foreground, to the left, outside the figure. In the middle distance in the center is a remnant of the Pembina delta with a road winding up from the valley. In the distance is the Pembina Mountain escarpment, rising above the delta.



Fig. 2. Heart Mound, in section 6, Fremont township. A remnant of Pierre shale on the high plain to the west of the Pembina Mountain escarpment.

of the first three the valleys fade out about ten miles west of the escarpment. The Little Pembina river does not pass into the Red River Valley region. It rises west of Stilwell and flows in a general northerly direction for about six miles where it turns to the southeast. On its emergence from the escarpment it runs east for a short distance in the Pembina delta, and then flows in a northerly direction a little west of the line between the escarpment and the delta until it joins the Pembina in section 34, Fremont township. Entering from Manitoba, the Pembina river runs in a deep valley through the upland west of the escarpment in a southeasterly direction. After leaving the escarpment it continues in a northeasterly direction to Walhalla, running through the Pembina delta, where its valleys varies from 100 to 200 feet in depth. The Little North river is the principal tributary of the Pembina river on the north. It enters from Manitoba, flowing in a general southerly direction to its junction with the Pembina in section 24, T. 163, R. 58. It has cut a deep valley, varying from 200 feet on the north to 450 feet on the south. In the majority of cases these streams drain a strip of land about three miles wide on either side. (See Plates XXI and XXII.)

This brings up a subject which may well be briefly considered here; namely, the age of the different valleys which are mentioned in this paper.

The smaller and shorter valleys are undoubtedly of post-glacial age. But about the Park, Tongue and Pembina rivers there may arise a doubt in the minds of many as to whether they are of post- or preglacial age. We are apt to think of glacial erosion as such a tremendous leveler of previously existing contours, that in surveying a glaciated area we ascribe all the minor features of erosional topography to post-glacial time. But in studying the various features of the above mentioned rivers one is struck by several features which undeniably point to a preglacial existence.

Primarily there is their great length and in many cases extensive bottom lands, such as we usually associate only with streams of considerable age. We must remember that geologically speaking there has elapsed only a short time since the retreat of the continental glacier, while to erode a valley the size of the Pembina valley is the work of a long period. Compare the length of the gorge of the Pembina with other gorges which are known to have

existed only since glacial times and the latter sink into comparative insignificance. And the Pembina valley can not be properly called a gorge; true it has steep, often precipitous sides, but it also has a well developed flood plain and in many cases shows remarkably good evidences of terraces. All this is not compatible with our conception of streams of recent origin. (See Plate XXII, Fig. 2.)

A second and much more conclusive evidence in favor of their preglacial origin is this: In many places on all three rivers, where a section exposing the drift and underlying Cretaceous strata was obtained, the drift next to the Cretaceous was perfectly fresh and unaltered while the Cretaceous itself was very much decomposed but yet preserving its main characteristics such as bedding and cleavage, in fact having all the characteristics of strata decomposed in situ. This invariably would occur on the north bank of the stream and often more than half way down the actual depth of the valley, where naturally the surface would be protected from erosion by the southward moving glacier, the lower surface not being sufficiently flexible to conform to the steeply pitching surface without decrease in erosive power and thus leave the weathered surface intact ready to receive its mantle of drift.

This was specially well revealed in the fresh railroad cuts, examined in the fall of 1908, where the spur of the Northern Dakota Railway Company follows the Tongue river valley to the Cement mines.

Thus it would seem that the occurrence of undoubted fresh drift upon decomposed Cretaceous strata, well down the side of a valley is conclusive evidence of that valley's preglacial existence. It may be mentioned that every place where the glacier had a good opportunity of eroding, as in the Red River Valley, the Cretaceous, where found in contact with the drift, is fresh and unaltered.

The high upland rolling prairie, which includes the greater part of Cavalier county, and lies to the west of the Pembina Mountain is imperfectly drained. There are a large number of intermittent sloughs, which contain water during the wet seasons of the year. These sloughs are formed by the collection of surface water in the depressions of the undulating surface. In the spring, a series of these sloughs will often contain water enough so that they may form a connection with drainage. This is well shown by the series running through T. 161, R. 61, and T. 162, R. 62, and which drains

north into Rush Lake. The lake in T. 163, R. 60, and Rush Lake are further evidence of this imperfect drainage. In dry summer seasons they do not occupy more than one-half of the area indicated on the map; and the remaining part affords excellent hay land. In wet seasons, these lakes have outlets to the north into the Pembina river. The stream shown in T. 163, and 164, R. 64, has a shallow coulee and drains northward into the Pembina.

GENERAL GEOLOGY.

In this portion of the report, the relations of the district under consideration to the neighboring parts of the continent are discussed and thus the general relationship as well as the details of the district itself are presented. For this reason it has been found necessary to introduce material that is foreign to the immediate topic, but which throws light on the broader aspects of the geology of the area.

The Red River Valley is characterized by the lacustrine silts, clays, and beach deposits of glacial Lake Agassiz. But the formations underlying these deposits and exposed by deep well borings are also of interest. Deep wells at Humboldt, Minnesota, Grand Forks, and Grafton, North Dakota, and Rosenfeld, Manitoba, have shown that rocks representative of the Archean and Paleozoic eras underly these lacustrine deposits.

The crystalline rocks of the Archean, which are chiefly granites, gneisses and schists, constitute the foundation upon which rest the later sedimentary formations. The Archean was reached at 638 feet at Humboldt, Minnesota, at 903 feet at Grafton, and at 1,035 feet above sea level at Rosenfeld, Manitoba. This would show that the surface of the Archean had a dip to the west and north of about twenty feet to the mile. These rocks probably form a part of the great Archean area of Canada and the Lake Superior region.

The Paleozoic era is represented in this area by the Cambrian and Silurian formation as shown by well records. The only evidence of the occurrence of Cambrian strata is furnished by the record of the well at Grafton. Here the Archean is overlain by 288 feet of shales and sandstone which are believed to belong to the Cambrian. Beds belonging to this age are found associated with the Silurian farther north in Manitoba, south and west of

Lake Winnipeg. They may or may not be continuous with the beds found in the Grafton well, since rocks of this age are absent in the wells at Humboldt and Rosenfeld. It is reasonable to suppose, however, that they were continuous at the time of their deposition.

Silurian. Silurian rocks underly a portion of the Red River Valley and form a wide belt extending along the western shore of Lake Winnipeg and to the northwest. Fragments of Silurian limestone, containing characteristic fossils, are not uncommon in the glacial drift. They were brought into the state by the continental glacier, probably from outcrops in Canada. In the Grafton well the beds referred to the Lower Silurian have a thickness of 317 feet, including the Galena and Trenton limestones, 137 feet, the Saint Peter sandstone, 93 feet, and the Lower Magnesian shales, 87 feet. In the deep well at Grand Forks, forty miles south, only one foot of Silurian limestone was encountered just above the granite. This may indicate either that the Silurian sea in which the strata were laid down did not extend far to the south or that, after having been deposited, the beds were eroded over this portion of their area, leaving only part of their original thickness. The Silurian formation appears to thicken quite rapidly toward the north, for while at Grafton, as already stated, it is 317 feet thick, sixty miles north at Rosenfeld, Canada, it has increased to 892 feet.

Although rocks of the Devonian period are, so far as known, absent from North Dakota, they cover a narrow strip of territory lying just west of the Silurian area of Manitoba. At Morden, at a depth of 412 feet, a well penetrated 188 feet of red and gray shales and porous limestone believed to belong to the Devonian. It is probable that these strata extend south some distance across the boundary.

CRETACEOUS

Cretaceous beds lie on the west border of the Archean rocks in Minnesota, and farther north, along the west side of the lower part of the Red River Valley and of Lakes Manitoba and Winnipegosis, they overlie the Lower and Upper Silurian and Devonian strata, which form the floor of this broad flat valley beneath its glacial, lacustrine and fluvial deposits. Thence northwestward to the Mackenzie river and the Arctic ocean, Cretaceous beds border and overlie the western border of the Silurian and Devonian belt.

The rocks of this period cover nearly one-half the state and are of great economic importance, containing valuable clays, cement rock, and artesian waters.

The Cretaceous beds of North Dakota are a part of a larger area which forms a broad belt lying east of the crest of the Rocky Mountains and extending north from Texas. They underlie the greater portion of the Great Plains region, though they are in small part covered by the later deposits of the Tertiary. The beds of this period are divided into the Upper and Lower Cretaceous, but only the Upper is found in this state.

The standard upper Missouri section of the Upper Cretaceous by Meek and Hayden¹ is here given:

- No. 5. Fox Hills group.
- No. 4. Fort Pierre group.
- No. 3. Niobrara group.
- No. 2. Fort Benton group.
- No. 1. Dakota group.

The elevation composed of Upper Cretaceous strata, forming at the south a massive ridge and at the north a bold escarpment, and bordering on the west the valley in which Lake Agassiz lay, is called in successive portions the Coteau des Prairies, Pembina, Riding and Duck Mountains, and the Porcupine and Pasquai Hills. It has mostly so thick and continuous a covering of glacial drift that only a few exposures of the underlying strata are seen, chiefly where channels have been eroded by streams. Throughout their extent of 800 miles the ridge and escarpment appear to consist mainly of the Fort Pierre formation, presenting a thickness of several hundred feet of dark shales, mostly soft and somewhat sandy. Under the Pierre beds are similar shales belonging to the Niobrara and Fort Benton formations, succeeded below by the Dakota sandstone, which is not exposed.

As stated later, the southernmost known exposure of Niobrara occurs on the North Branch of the Park river, where it leaves Cavalier county, about three miles north of the Walsh-Cavalier boundary line, in the northeast quarter of section 13, T. 159, R. 57. The South Branch of the Park river was visited and a cursory examination made of a few of the better exposures, but no Niobrara outcrops were found, but judging by the Pierre, which was exposed

¹Proc. Acad. Nat. Sci. Phila., Vol. 8, 1856, pp. 265-266.

just above the river, the top of the Niobrara was about twenty-five to thirty feet below the lowest point the river has eroded before it leaves the escarpment. There are some very characteristic layers in the lower part of the Pierre, which seem to be harder and more resistant than the rest. They vary from an inch up to a foot in thickness, and consist mainly of shale highly indurated with iron which cements the minor cleavage cracks and makes the shale form a concretionary structure. Where these layers occur they protect the underlying softer formation from erosion, thus forming little shelf-like projections, very noticeable wherever they are well exposed. They invariably occur near the bottom of the formation, and it is from this fact that it is believed that the Niobrara is twenty-five to thirty feet below the present stage of erosion of the South Branch of the Park. This would give an elevation to the top of the Niobrara of not more than 1,125 feet above sea level. It may be less.

Beginning with the South Branch of the Park river on the south and ending with the Pembina on the north, there are several creeks that have eroded quite deep yet narrow valleys which cut the cliff perpendicularly to the face. It is along these that the only prominent exposures of the Upper Cretaceous occur. As a general rule the valleys become deeper as we advance north along the edge of the escarpment; or probably a more correct way to state this apparent fact would be to say, that as we go northward the valleys extend deeper down into the Cretaceous strata. This is much more noticeable than the increase in the actual depth of the valleys. The cause of this is not so much that the rivers on the north have greater erosive power as the difference in elevation of the Cretaceous formations, the top of the Niobrara being about 250 feet higher on the Pembina than on the South Park.

There is a possibility of the existence of a shelf of Upper Cretaceous strata extending east from the escarpment for some distance under the Red River Valley. This is shown by the possible occurrence of the Dakota sandstone at Park river, and the occurrence of the Benton and Niobrara in many wells about a mile east of the escarpment. (See Plate XXIV.)

DAKOTA SANDSTONE.

At the base of the Upper Cretaceous lies the Dakota sandstone, which is of great economic importance in North and South Dakota as the source of artesian water. This formation does not outcrop



Fig. 1. View on Pembina river, showing the outcrops of Niobrara beds.



Fig. 2. View from bridge on Pembina river, showing outcrops of upper Cretaceous beds at the plant of Mayo Brick & Tile Company. The steep part of the bluff is Niobrara; the lower shelving part is Benton.

anywhere in the state, and lies at considerable depth below the surface. In the eastern counties it has been struck at depths varying from 1,000 feet and less to 1,450 feet. The Devils Lake well reached the sandstone at 1,431 feet and at Jamestown it was encountered at a depth of 1,450 feet, while further south it lies nearer the surface. The water enters the formation where it outcrops along the flanks of the Rocky Mountains and Black Hills, and since the beds dip towards the east it finds its way through the porous sandstone to a great distance from the surface exposures. The rock becomes saturated with water and serves as a reservoir for the artesian supply. This formation is a very persistent and readily recognizable horizon.

In the absence of exposures within the state, information concerning the character of this formation is derived partly from descriptions of it as found elsewhere and partly from the records of deep wells. The rock is a gray and brown sandstone containing layers of clay or shale. At the base of the formation there is sometimes a conglomerate. The sandstone varies from that which is quite firm to loose sand which is barely consolidated and is frequently so soft as to be readily excavated with a pick. Fossil leaves are very abundant in places, and the flora of the Dakota sandstone includes no less than 450 species of trees and other plants resembling those of today.

The thickness varies widely at different points, but it is seldom more than 500 feet, and is commonly less. At Morden, Manitoba, twenty-five miles northwest of Walhalla, the deep well record shows that the Dakota is ninety-two feet thick, formed of sandstone with interbedded shales and resting on Devonian strata. Elsewhere in the same district outcrops of the sandstone and wells penetrating it show that its thickness varies from 50 to 150 feet.

The beds of the Dakota formation are commonly regarded as of fresh water origin on account of the fresh water shells and abundant remains of land plants contained in them. In Texas and Kansas, however, marine forms are found and indicate marine conditions in those districts. The sandstone was probably formed in large bodies of fresh water, the materials composing it being derived from the Rocky Mountain region on the west. The waste from the land was gathered and transported by streams and deposited in these lakes, where it gradually accumulated to form the sandstone strata.

It is possible that the eastward extent of the Dakota sandstone beneath the Red River Valley is greater than previously supposed. Mr. George Honey of Park River reports that in the well at the flour mill at that place, after passing through hard pan at 300 feet, the drill struck a white sandstone formation which gave water rising to within eighty-five feet of the surface.

COLORADO FORMATION.

Overlying the Dakota sandstone is the Colorado formation, including the Benton and Niobrara shales and limestone. These record a vast invasion of the interior region by the sea. The eastern limit of the Dakota in our latitude was probably in an approximate line with the present course of the Red river. The Colorado, however, perhaps extended eastward almost to the Mississippi, for in many places in the basin of the Upper Mississippi throughout Minnesota, Iowa and Wisconsin, there occur isolated patches of deposits which are considered Cretaceous. These may have been continuous once with the formations to the west, the intermediate regions being entirely denuded of Cretaceous beds by erosion; or they may have been originally isolated, but they have so many characteristics in common with the corresponding formations further west that it is reasonable to consider them as outliers of these formations. Thus in Iowa there occurs a formation referred to the Niobrara series of the Colorado which in composition and appearance is almost identical with that formation as it is found in North Dakota.¹

Two divisions of the Colorado are recognized, the Benton below and the Niobrara above. The Benton consists of shale principally while the Niobrara is chiefly calcareous shales and limestones. Both are relatively shallow marine deposits. So far as yet known their outcrops within the state are confined to Cavalier and adjoining portions of Pembina counties. The Niobrara outcrops in several places along the gulches that extend two or three miles along the eastern edge of the Pembina Mountain as well as along the banks of the rivers.

BENTON.

The Benton shale outcrops in only a few places along the Pembina river, none of the other streams having cut through the overlying Niobrara. (See Plate XXIV.) It is reported by the Cana-

¹Calvin, Iowa Geol. Surv., Vol. III, 1893, pp. 213-236.



Fig. 1. Exposure of Benton shale on Pembina river in section 36, Fremont township. This is the easternmost outcrop under the delta. Shows concentration of boulders in stream.



Fig. 2. Typical exposure of Pierre shale. In northeast quarter section 15, North Loam township. A concretionary hard layer is shown half way up the slope.

dian geologists to occur quite extensively to the north. The following brief description given by them serves to illustrate its general character:

"Overlying the Dakota sandstones, the Benton occurs as a band of dark gray, almost black shale, holding a considerable quantity of carbonaceous material. This shale is evenly bedded and breaks readily into thin flakes, on which account it generally has sloping banks. In the base on Vermillion river, the Benton appears to be 178 feet thick and further north on the face of the Duck and Porcupine mountains, it is continuously of the same or slightly less thickness. It is easily recognized even when good sharp exposures are absent by its characteristic property of breaking into more or less minute graphite-like flakes and not weathering immediately into a soft clay as usually occurs in the less consolidated bed of the river. It is generally quite destitute of fossils but in a few places undeterminable fragments of oysters and inocerami have been collected from the shale."¹

The Benton in most exposures has weathered to a very plastic and unctuous clay which is difficult to distinguish from common residual clay. The only sure way of determining whether it is Benton is to find the contact with the Niobrara above. The strong petroleum odor of the Benton serves in some cases to distinguish it from residual or alluvial clays. The Benton is reported in places to grade insensibly upward into the Niobrara but wherever the contact was seen in this region there was found a good, clean and distinct line of separation, unmistakable when once seen. The physical character of the two is very dissimilar. The Benton is soft, very fissile and becomes plastic on the addition of water. The Niobrara is comparatively hard, breaks with a conchoidal fracture and ordinarily does not become plastic, even on long exposure to weathering influences. The contact between the two may be likened to the result obtained by sticking a lump of soft putty on the under side of a hard brick; the putty separates easily leaving the brick projecting over the edge. Thus the Benton can be dug from under the Niobrara leaving the latter projecting as a sharp and well defined edge. (Plate XXVI, Fig. 1, and Plate XXVII.)

¹Tyrrell, Ann. Rept. Can. Geol. Surv., Vol. V., part I, report E., p. 210.

The Benton shales have been used for brick making by the Mayo Brick and Tile Company whose plant is located on the north bank of the Pembina at its confluence with the Little Pembina river, section 33, T. 57, R. 163. About 150 feet of shale are found here, but of these only the lower part is suitable for brick making.

C. H. Clapp describes the properties of this clay as follows: "It is of a gray color when dried, is almost black when freshly exposed and contains many dark carbonaceous particles. Small ferruginous concretions are also abundant. Pyrite is found in small quantities, being reduced by the abundant carbonaceous matter. In the lower beds some of the carbonaceous material has been distilled and the clay has a strong odor of petroleum. The clay is fine grain-
ed with very little grit, but the concretions are more sandy."

He also gives the following analysis of a sample collected near the top of the formation:

	Per Cent.
Silica	69.90
Alumina	10.66
Ferric oxide	2.32
Lime	1.07
Magnesia	2.10
Volatile matter	6.09

The clay is manufactured into good hollow brick and drain tile which should find a ready sale in the Red River Valley.

The following detailed sections show the character of the Benton and its relation to the overlying Niobrara:

Outcrop of Benton and Niobrara shale on the Pembina river at the plant of the Mayo Brick and Tile Company.

	Feet. Inches.
8. Glacial drift	3-5
7. Clay, yellowish, containing two yellow bands, much weathered	2
6. Clay bands, yellow and black	3
5. Shale, calcareous, "cement rock"	15
4. Clay band, yellow	3
3. Shale, calcareous, "cement rock," various layers, more or less weathered but well exposed, Niobrara	165
2. Shale, black, Benton	15
1. Unexposed to river	140

The lower 140 feet of this section referred to as unexposed may be only slightly weathered Benton shale as it is difficult to distinguish the fresh shale from some varieties of residual clay. The contact between the Benton and the Niobrara is at this place very sharp and easily seen in two or three different places. There were some springs issuing from the bluff at the contact.

The Benton is here a rather soft and plastic clay shale, much softer than either the Niobrara or the Pierre. It is black in color but weathers to medium gray. It contains considerable iron pyrite, which in a fresh cut sample can be seen glistening in the dark colored clay. It does not have as marked a petroleum odor as does the Niobrara above. The Niobrara at the contact is coarse-grained and hard, and contains some sand. The Benton can be dug away from beneath the Niobrara and parts from it very easily, leaving a hard projecting ledge with a smooth even surface.

The Pembina delta has been referred to previously in this report from the topographic view point. Dr. C. P. Berkey pointed out in his paper on the region that the Benton probably extended to the east beneath the delta deposit. In examining the exposures along the Pembina river from the Mayo plant down to Walhalla, various outcrops of the Benton overlain by till were found. The last exposure was on the north bank about one-third of a mile east of the western boundary of section 36 Fremont township. At this point there was an exposure of about twenty feet of Benton. This was immediately overlain by till, and a careful examination of the thickly overgrown bluff showed that the till was about twenty-five feet thick, and was overlain by gravel to the top of the bluff. Toward the east the till soon sinks below the level of the river and is succeeded by the overlying delta deposit of gravel, sand and finally fine silt in the southeast quarter of section 29, Walhalla township. (See Plate XXV, Fig. 1.)

In the valleys of the Little Pembina, Pembina and Little North rivers there is a thick growth of brush and weeds, and many slides from the bluffs have partially choked the valleys in places. The drift of the region is quite free from boulders. The latter are very plentiful, however, in the valleys of these streams, where they have been left as the concentrates of the sizing action of erosion.

Outcrop of Benton and Niobrara beds on south bank of Pembina river at the "Fish Trap," near the middle of the northern boundary of section 30, T. 163, R. 57.

	Feet. Inches.
6. Soil	3-4
5. Gravel, coarse, containing glacial boulders of igneous rock and many fragments of Pierre shale.....	30
4. Sand, fine, with thin layers of clay well stratified	30
3. Shale, calcareous, "cement rock"	10
2. Shale, black, Benton	50
1. Unexposed	90

This outcrop is remarkable inasmuch as it occurs well up on the "second mountain" and yet all of the Niobrara is eroded away with the exception of ten feet. Near by on the opposite side Pierre shale occurs, which would indicate the Niobrara is there uneroded.

A short distance above the Fish Trap a small stream enters from the north. This is called the Little North river. It has a deep but narrow valley, and cuts from the Pierre through the Niobrara into the Benton in its short course from the international boundary to its junction with the Pembina river.

An outcrop appearing in the southwest quarter of section 18, T. 163, R. 57, shows the following section:

	Feet. Inches.
6. Unexposed to top of bluff	
5. Shale, calcareous, "cement rock"	70
4. Unexposed	35
3. Shale, calcareous, "cement rock"	25
2. Shale, black, Benton	20
1. Unexposed	25

The cement rock contains numerous small bands of limonite or clay highly stained with ferric oxide. The crevices and fissures in the rock are also stained. The contact between the Niobrara and Benton is very well marked here.

NIOBARARA.

The Niobrara outcrops at numerous localities throughout the Pembina Mountain region as far south as the North Branch of the Park river. It is exposed in nearly every gully from the Park north to the boundary. It is reported by the Canadian Survey as outcropping all along the northward continuation of the Pembina escarpment and in the Tiger Hills. North of the Assiniboine river it occurs in Riding and Duck mountains and in the Pasquia Hills. It is undoubtedly continuous throughout this region and it has very much the same characteristics wherever seen. Dr. A. G. Leonard reports the occurrence of similar beds on the Sheyenne river near Valley City which he thus describes¹: "Both in appearance and composition it is distinctly unlike the beds referred to the Pierre. The clay outcrops near the base of the cut along the Soo railroad one and a quarter miles east of Valley City, where twenty feet of light gray and cream colored clay appear. The same light colored calcareous clays are seen along the bluffs of the Sheyenne river, at the sharp bend one mile south of town, where the stream

¹Fourth Biennial Report, N. Dak. Geol. Surv., p. 101.



1. Typical Benton rock, freshly exposed, at the Mayo plant. The shale yields conchoidal fragments under the pick.



Fig. 2. Typical Niobrara shale on the Little Pembina north of Olga. The long splintery conchoidal fracture is distinctly shown.



Contact of the Benton and Niobrara at the Mayo plant. The underlying Benton is soft and sticky; the overlying Niobrara more fissile; while the contact is sharply defined by an arenaceous layer.

cuts against the bluff. Here are exposed 100 feet of light gray clay breaking into thick irregular pieces and overlain by twenty feet of black shale which is undoubtedly Pierre." The following analysis of a sample from the upper layers is given by the same writer. The sample was air dried only.

	Per cent.
Carbonate of lime	45.00
Carbonate of magnesia	3.00
Silicia	30.70
Iron and aluminum oxides	15.20
Moisture and undetermined	6.10
Total	100.00

This analysis shows a close resemblance to those of typical Niobrara but is higher in silica and lower in lime than the average. However, the beds vary much in composition, ranging from forty to eighty per cent of lime carbonate. But even forty per cent is much too high a lime content for any of the Pierre shales since the most calcareous of them do not approach that limit.

The rock constituting the greater part of the Niobrara is very easily recognized by one familiar with its characteristics. It is a dark gray, moderately hard, calcereous shale. It contains numerous small white specks of lime which cause it to have a finely mottled appearance which is plainly seen on a fresh fracture. It appears that its lime content is due almost entirely to minute Foraminifera, of which a great number may be observed under the microscope. Dr. A. G. Leonard has determined two varieties of these in specimens collected by him. These are *Globigerina cretacea* and *Textularia globulosa*, both of which are common in the Niobrara deposits wherever found. They constitute the greater part of the chalk of the European Cretaceous. The theory as to the origin of chalk is as follows:

"There has been much difference of opinion concerning the origin of chalk. Its resemblance to the foraminiferal ooze of the deep seas long since led to the belief that it was a deep sea deposit; but closer examination has thrown doubt on this conclusion, for it appears that the points of difference between the chalk and foraminiferal ooze are as striking as the points of resemblance. Both consist largely of the shells of minute protozoans, largely foraminifera; but with them are associated shells of other types, some of which are similar in the two formations and some dissimilar. The

echinoderms, the sponge spicules, and the shells of some microscopic plants found in the chalk, seem to correspond in a general way to those of the oozes now forming and are consistent with the deep water origin of chalk. The molluscan shells of the chalk on the other hand seem to point with clearness to water no more than thirty to fifty fathoms deep. The distribution of chalk, and its relation to other sedimentary beds, seem to point to its deposition in water of moderate depth rather than in water corresponding in depth to that in which the oozes are now found. That chalk may originate in shallow water seems to be clearly indicated by various facts which have been observed in connection with coral reefs past and present."

"Another point in difference between chalk and foraminiferal ooze is found in their relative proportions of lime carbonate, the proportion being much higher in chalk than in ooze. The elevation and exposure of the chalk can hardly have led to this difference, for the extraction of the relatively soluble lime carbonate, must have increased the percentage of the relative insoluble impurities. On the other hand, the analysis of chalk, used in this comparison may have been from the purer portions of the formation and since chalk grades off into chalky clay and chalky sandstone, varieties of chalk containing no more lime carbonate than the oozes, are doubtless to be found in abundance."

"One of the peculiarities of the chalk beds is the presence in them of abundant nodules of flint and chert, which are not present in the modern deposits resembling the chalk. These nodules seem to have resulted from the subsequent concentration into concretions of the siliceous material (sponge spicules, etc.), deposited with the calcareous shells which make up the body of the chalk. On the whole, the balance of evidence seems to favor the hypothesis that the known chalk deposits were made in relatively shallow water. The conditions for the origin of chalk seem to have been clear seas with a genial climate. Foraminiferal shells may accumulate as well on the bottom of a shallow sea as on the bottom of a deep sea. The purity of chalk depends not on the depth of the water, but on the absence of clastic sediments."¹

The deposits of the Niobrara in which foraminifera are found vary in composition from forty to ninety-five per cent of lime carbonate, or from nearly pure chalk to a highly calcareous shale.

¹Chamberlin and Salisbury, *Geology*, Vol. III, pp. 149-150.

This goes to show that the foraminifera exist in water ranging from that which is clear to that in which active sedimentation is taking place. The continual presence of molluscan shells, however, shows that this water never became deep in comparison with the open ocean of today.

With the change in composition a corresponding change in the texture of the rock occurs. Pure chalk is soft and exceedingly friable, but with an increase in the clay content it becomes more firm, assuming a dense, massive structure, breaking with difficulty with a sharp, clean conchoidal fracture. It shows no fissility like shale but upon drying on exposure to the air it tends to part along bedding planes. This property is not so well developed, however, but that it requires considerable force to break a fragment of dry rock even if very porous and apparently cracked in appearance. With an increase of the clay content above fifty per cent it begins to assume the more characteristic properties of shale. It is not so firm and compact; it weathers more easily and crumbles down on exposure to the air.

Wherever the Niobrara is exposed in the Pembina Mountains it maintains a fairly uniform character throughout its thickness of 150 feet or more. By far the greater portion of the aggregate thickness is composed of a dark, bluish-gray mottled rock which varies from fifty-five to sixty-five per cent of lime carbonate in passing from one layer to another. This change in composition does not seem to alter the physical appearance of the rock to any great degree. Generally the more mottled the rock appears the higher it is in lime. Between these thick layers of rock high in lime carbonate are others much thinner, varying from a few inches to a foot in thickness, which are much lower in lime. They have a clayey appearance and occur in no regular order. These layers, both the thick massive ones and the thin clay seams, are lenticular in shape and vary much in thickness from place to place, and may entirely pinch out within a short distance. (See Plate XXVI, Fig. 2.) This indicates rather unstable conditions of sedimentation and shifting sea currents. However, the aggregate thickness of the Niobrara is much more constant than that of the individual layers. The total thickness is about 165 feet where the entire formation is exposed in North Dakota. At Morden, Manitoba, the beds are 160 feet thick and farther north they average from 150 to 200 feet in

thickness, an extreme of 500 feet being reported at Thunder Hill, Manitoba. This is in the northwestern part of the province and they reach this thickness only in this one place. It is possible that the upper part of the beds here belongs to a calcareous member of the Pierre shale.

The beds seem to thicken toward the west for at Deloraine a well reached the top of the Niobrara at an elevation of 569 feet above the sea level and the base at twenty-four feet above sea level, thus giving to the Niobrara a thickness of 545 feet.

The ease with which the Niobrara may be recognized, especially the top layers, makes it an excellent datum plane to work from in the field. Its top along the Pembina, Porcupine, Riding and Duck mountains maintains an approximate height of 1,200 feet above sea level. The beds seem to dip toward the southwest at a very low angle, probably not exceeding four feet to the mile, which might well correspond to the slope of the sea bottom on which they were laid down. In general the dip of the Niobrara as a whole seems to be southwest, but this is at such a low angle that it is impossible to note the dip on any single exposure. The beds as before stated average about 1,200 feet above sea level along their eastern edge from the Park river northward to Lake Winnipegosis in Manitoba. But at Deloraine in Manitoba, just north of the Turtle mountains, their top has an elevation of 569 feet, denoting a dip of about four feet to the mile.

At a distance of about a mile east of the Pembina escarpment and extending from immediately south of the Pembina delta to the vicinity of Edinburg, the Niobrara has been encountered in various wells at depths ranging from 60 feet at the north to 150 feet at the south. This cannot properly be called an eastward extension beneath the Red River Valley on account of its proximity to the escarpment, but it does indicate at least a terrace or a shelving off of the strata to the east due to erosion by the Red river previous to the glacial period.

The following sections show the details of the Niobrara, together with its relation to the Pierre above and the Benton below:

On the North Branch of the Park river there are numerous well exposed outcrops of Pierre shale and one outcrop of the underlying Niobrara. This occurs on the southeast quarter of section 13, T. 159, R. 57, where the following section appears:

	Feet.	Inches.
10. Glacial drift	15-20	
9. Shale, black		6
8. Clay band, yellow		4
7. Shale, black		7
6. Clay band, yellow, similar to No. 4.....		2
5. Shale, similar to No. 3	12	
4. Clay band, yellow, which becomes dark blue at a distance varying from one to two feet from the surface		6
3. Shale, very dark, carbonaceous, which has marked petroleum odor and weathers into small fragments. Contains numerous seams highly stained by ferric oxide	15	
2. Shale, calcareous, "cement rock"	6	
1. Unexposed to waters edge	10	

No. 2 of the above section resembles in every particular the so-called "cement rock" mined on the Tongue river by the Northern Cement and Plaster Company. It breaks with a conchoidal fracture, but has no regular cleavage along bedding planes, though generally it is traversed by numerous fissures, mostly at right angles to the bedding. It resists the action of water but crumbles very easily when dry. A marked feature is a strong odor of petroleum which is always found in connection with the fresh rock.

A sample collected from this outcrop yielded the following results upon chemical analysis.

	Per cent.
Silicia	13.72
Alumina	5.38
Ferric iron	2.41
Calcium carbonate	64.20
Magnesia	0.73
Sulphur trioxide	0.75
Carbonaceous material	8.00

This is the southermost natural exposure of the Niobrara in this region. Half a mile to the south a well passed through practically the same succession of layers and seven or eight miles further south or about four miles west of Edinburg a deep well struck the Niobrara after passing through 150 feet of Pierre shale.

No. 3 and succeeding yellow layers consist of a very peculiar yellowish clay. It is very soft and free from grit, strongly resembling cheese in its texture. Unlike most clay however it is absolutely devoid of plasticity, crumbling down into an incoherent mass when moistened. When unweathered it is dark bluish but on exposure to air turns very quickly to a yellow color, probably on account of the rapid oxidizing of the ferrous salts which in contains. It tastes strongly of alum and analysis reveals a

high percentage of sulphates, but whether they are combined with sufficient alkalies to form true alums has not been determined. In physical appearance these layers resemble the "Bentonite" found in the Benton and Niobrara on the Vermillion river in northwestern Manitoba. The layer is there about thirty inches thick, while numerous thinner layers are distributed all through the Niobrara. On the Tongue and Pembina rivers a single layer of the same material was found well up in the Pierre. This seems to give to these layers a wide vertical as well as a wide horizontal range.

Very peculiar conditions of sedimentation must have existed when these layers were deposited. These can only be briefly discussed here, but it has been suggested that one condition under which similar deposits might be formed would be as follows: That for some time there existed very quiet seas, free from currents and not much disturbed by winds. These became heavily charged with alum which served to settle all fine particles held in suspension by the water, as well as serving as a precipitating agent for various salts held in solution. The strong alum taste of the shales, their fine, uniform character and wide extent tend to support this theory, and the settling properties of alum have long been well known.

A very interesting exposure occurs in the southwest quarter of section 24, T. 160, R. 57.

	Feet.	Inches.
7. Unexposed to top .....	..	..
6. Glacial drift	4	
5. Shale	5	
4. Clay band, yellow		2
3. Shale	25	
2. Clay bands, yellow and black	57	
1. Shale, calcareous, "cement rock"	6	

An eighty-foot tunnel has here been driven in on a level with the yellow and black bands so that they are better exposed at this point than anywhere else, and their peculiar features can more readily be examined. Here also a bore hole was put down to a depth of 150 feet below No. 1 of the above section. At a depth of 150 feet the cement rock had not been passed through, but at that depth a hard layer was struck which the auger could not penetrate.

The two-inch yellow seam (No. 4) which is found in the Pierre twenty-five feet above the main horizon of black and yellow layers is identical in appearance to the yellow bands below.

An exposure occurring further down this same valley and near the Cavalier-Pembina county boundary line, shows the following section:

	Feet.	Inches.
11. Clay and soil with many seams of limonite and gypsum	6	
10. Clay bands, yellow and black	5	
9. Shale, calcareous, "cement rock"	4	
8. Limonite		1
7. Shale, calcareous, "cement rock"	6	
6. Limonite		1
5. Shale, calcareous, "cement rock"	4	
4. Limonite		1
3. Shale, calcareous, "cement rock"	5	
2. Shale, calcareous, weathered and bleached	2	
1. Shale, calcareous, "cement rock"	3	

No. 2 resembles chalk but it undoubtedly only a weathered variety of cement rock. The outcrop was in a very sheltered place where rain and wind could not easily reach it to wash away the weathered surface. A similarly situated outcrop was found on the Pembina river, and it also had the appearance of chalk on the surface, but on digging into the bank the layer gradually lost its chalky appearance and assumed that of the typical cement rock.

The limonite layers also seem to be a product of this peculiar weathering process for in no other place were they found as here. They probably originated from some highly ferriferous clay layer, from which the more soluble constituents had been washed away. These clay layers occur at intervals throughout the cement rock and weather more readily than the rock itself.

Section found in northwest quarter of section 13, T. 160, R. 57.

	Feet.	Inches.
4. Unexposed, and drift to top of bank	50	
3. Shale	20	
2. Clay bands, white and black	4	
1. Unexposed	20	

Farther west and half a mile upstream, the following section was exposed:

	Feet.	Inches.
6. Drift, to top of bank		
5. Shale	35	
4. Clay seam, yellow		2
3. Shale	25	
2. Clay bands, white and black	5	
1. Unexposed	8	

Section occurring in the northwest quarter of section 12, T. 160, R. 57.

	Feet.	Inches.
7. Unexposed to top	300	
6. Shale	7	
5. Clay band, yellow		2
4. Shale	25	
3. Clay bands, yellow and black	4	
2. Shale, calcareous, "cement rock," with layers of limonite which vary from $\frac{1}{4}$ to 1 inch in thickness	6	
1. Shale, calcareous, "cement rock"	4	

At this point the edge of the Pembina escarpment reaches its greatest elevation and on that account the sides of the valley in which this outcrop occurs are higher even than those of the Tongue or Pembina valleys though the latter rivers have cut down deeper into the geological section, as will be seen by referring to the outcrops occurring on those streams.

When driving over the level and apparently unbroken plain which stretches back westward from the escarpment one often comes suddenly and without warning to the very brink of these deep and steep sided ravines.

The scene from the edge of one of these canyons, and not far from the summit of the escarpment, is most attractive and picturesque, for the eye looks down on the green, forest covered sides of the gorge and out over the fertile Red River Valley, dotted with fields of waving grain.

Outcrop on Tongue river at the plant of the Northern Cement and Plaster Company.

	Feet.	Inches.
10. Unexposed to top of bluff		
9. Shale	3	
8. Clay seam, yellow		2
7. Shale	1½	
6. Clay seam, yellow		1
5. Shale	21	
4. Clay bands, alternating yellow and black—12 yellow bands	5½	
3. Shale, calcareous, "cement rock"	18	
2. Clay seam, yellow		7
1. Shale, calcareous, "cement rock," various layers to bottom of river	63	

The rock underneath the alternating yellow and black bands is very heavily stained with iron along all cracks and joints. It also seems to be more massive than any of the layers below. The Pierre shale (Nos. 5-10) is full of selenite crystals of varying sizes, some specimens being perfectly crystallized, others assuming the shape of the cracks in which they are formed.

The workings of the cement company reveal very well the character of the cement rock at this place. One tunnel extends nearly nine hundred feet into the face of the bluff and discloses two small faults or slips whose strike is approximately north. They dip at an angle of about seventy-five degrees from the horizontal, both dipping west. They have finely developed fault planes and the surface where the slip has occurred is very smooth and polished. These displacements show that at one time or another there has been some slight disturbance, perhaps a slight folding with subsequent faulting.

The different layers of cement rock vary widely in composition. They may show the following or even greater range in chemical composition:

	Per cent.
Calcium carbonate	35-80
Silicon dioxide	12-25
Ferric oxide	3-7
Aluminum trioxide	4-9
Magnesium carbonate	0-2
Sulphur trioxide	0.25-0.85

A remarkably uniform and fine-grained layer, at present being used for the manufacture of cement, has the following composition:

	Per cent.
Calcium carbonate	64.00
Silicon dioxide	14.75
Alumina and ferric oxide	7.00
Magnesium carbonate	trace
Sulphur trioxide	0.65

This material when properly burned and ground makes cement which in comparison with the average Portland brands leaves very little to be desired. The material is easily mined, it breaks with a clean roof and floor, and requires comparatively little timbering.

Outcrop in the southeast quarter of section 11, T. 161, R. 57.

	Feet.	Inches.
7. Unexposed to top of bluff		
6. Shale	6	
5. Clay seam yellow		2
4. Shale, Pierre	10	
3. Unexposed	15	
2. Clay bands, yellow and black	6	
1. Shale, calcareous, "cement rock"	13	

A mile east of the old McLean Post Office, on the same creek as the above exposure, the black and yellow bands are exposed in a cut recently made in improving the roadway, on the north bank

of the creek. They are much decomposed but easily recognized upon examination, and are covered with about five feet of sand and soil.

Nearly five miles due north of this place, in the Pembina delta a deep well struck cement rock at a depth of sixty feet. About six miles south and one mile east of McLean cement rock was struck at thirty feet. This seems to show that the Niobrara exists quite generally under the drift and lacustrine deposits of the Red River Valley at some distance east of the escarpment.

Around McLean there is a large district which is copiously furnished with springs of pure sparkling water. These issue at the contact of the drift with the underlying Niobrara, which is hard and compact, being impervious to the water which sweeps along the upper surface of the gently eastward sloping Niobrara.

Outcrop on Little Pembina river in the southwest quarter of section 3, T. 162, R. 57.

	Feet.	Inches.
6. Gravel and quite large glacial boulders	20	
5. Clay band, yellow		2
4. Shale, calcareous, "cement rock"	15	
3. Clay seam, yellow		6
2. Shale, calcareous, "cement rock"	80	
1. Unexposed	40	

This section occurs on the east bank of the Little Pembina and is thought to be a part of the Pembina delta. The delta deposit, however, is very thin here in comparison with its thickness farther east. The delta ends toward the east in a high steep bluff locally known as the first mountain.

Outcrop on the Little Pembina in the northwest quarter of section 10, T. 162, R. 57.

	Feet.	Inches.
8. Unexposed to top, gravel and sand		
7. Clay bands, yellow and black	5	
6. Clay band, black		9
5. Clay band, yellow		2
4. Shale, calcareous, "cement rock"	15	
3. Clay seam, yellow		6
2. Shale, calcareous, "cement rock"	75	
1. Unexposed	35	

Outcrop on the Little Pembina, on north bank at the point where it turns north after leaving the escarpment, southeast quarter of section 22, T. 162, R. 57.

	Feet.	Inches.
6. Clay bands, yellow and black, much weathered and exposed under the overlying black loam	3	
5. Shale, calcareous, "cement rock"	15	
4. Clay seam, yellow		6
3. Shale, calcareous, "cement rock"	1½	
2. Clay seam, yellow		1
1. Shale, calcareous, "cement rock"	85	

Section on Little Pembina in the southwest quarter of section 21, T. 162, R. 57.

	Feet.	Inches.
8. Unexposed	100	
7. Shale	30	
6. Clay band, yellow		2
5. Shale	30	
4. Clay bands, yellow and black	8	
3. Shale, calcareous, "cement rock"	18	
2. Clay band, yellow		7
1. Shale, calcareous, "cement rock"	35	

Outcrop in the southwest quarter section 20, T. 162, R. 57.

	Feet.	Inches.
5. Unexposed to top of bluff		
4. Clay bands, yellow and black	6	
3. Shale, calcareous, "cement rock"	12	
2. Clay band, yellow		7
1. Shale, calcareous, "cement rock"	12	

Where this section is exposed a four inch seam of coal was said to occur, but it could not be found. A six inch seam of red earthy hematite is reported in this vicinity and samples of the hematite were seen which seemed to be pure and in no way inferior to the common grades of red ochre sold for paint. Locally it is used to some extent for paint. No definite information could be secured regarding the location of this deposit.

Outcrop on the Little Pembina in the southwest quarter of section 19, T. 162, R. 57.

	Feet.	Inches.
5. Shale	150	
4. Clay band, yellow		2
3. Shale	35	
2. Clay bands, yellow and black	10	
1. Shale, calcareous, "cement rock"	10	

In this exposure the thickness of the different layers may be distorted for the whole bank had the appearance of having slid bodily toward the river. It is the last outcrop on the Little Pembina in which any of the Niobrara occurs. There are numerous fine outcrops of Pierre for some miles farther up the river and along some of its branches.

Section on the Pembina river in the southwest quarter of section 3, T. 163, R. 58.

	Feet.	Inches.
7. Unexposed to top, about	50	
6. Shale, gray, Pierre	80	
5. Clay bands, yellow and black	9	
4. Shale, calcareous, "cement rock"	15	
3. Clay band, yellow		3
2. Shale, calcareous, "cement rock"	50	
1. Unexposed about	200	

Section of beds on the Pembina river in the southeast quarter of section 4, T. 163, R. 58.

	Feet.	Inches.
9. Unexposed to top of bluff		
8. Shale, gray, Pierre	15	
7. Clay band, yellow		2
6. Shale, Pierre	30	
5. Clay bands, yellow and black	9	
4. Shale, calcareous, "cement rock"	15	
3. Clay seam, yellow		5
2. Shale, calcareous, "cement rock"	150	
1. Unexposed	40	

Some of the lower forty feet may be Benton shale, but as the fresh rock was hidden by talus dropped from above its reference to the Benton is uncertain, although from the thickness of the Niobrara in other places, the Benton should appear near river level, though the Niobrara may be thicker here than farther to the east.

It is generally difficult to find good outcrops down close to the river, since for some distance the bluffs rise gradually, often as much as 150 feet, before the steep well exposed portions appear which contain the outcrops.

Section on the Pembina river in the southwest quarter section 29, T. 164, R. 58.

	Feet.	Inches.
8. Unexposed to top of bluff		
7. Shale, gray, Pierre	50	
6. Unexposed	40	
5. Clay bands, yellow and black	5-15	
4. Shale, calcareous, "cement rock"	15-25	
3. Clay band yellow		5
2. Shale, calcareous, "cement rock"	90	
1. Unexposed	100	

A great slide had just recently occurred in this place when this outcrop was examined. This had exposed over a hundred feet of Niobrara, but unfortunately the whole bluff was very much faulted, so much so that in no two places did the layers present the same appearance or thickness, the whole mass being much distorted and disturbed. It is the first exposure of the Cretaceous on the Pembina after it leaves Canada. The valley here appears quite

as large as it does at Mr. Mayo's place, where the Little Pembina enters the Pembina. It is wide and deep. Its bottom is usually timbered and overrun by vines and tangle weeds. The bluffs are timbered with small poplar, while upon the level sides larger poplar with an occasional oak or other hardwood trees abound.

On looking over the foregoing sections of Niobrara beds the reader will be struck with their similarity over wide areas. Some of the overlying yellow clay bands have been traced continuously a distance of thirty-five miles and a single band two inches thick for twenty-five miles. Over all this area they have very nearly the same thickness and the same chemical composition.

In the Duck Mountains of Manitoba one of the writers has seen several outcrops of Niobrara along the Wilson and Valley rivers, and in these the same overlying yellow bands appeared, not in the same order or thickness, but nevertheless the identical bands. They thus appear to be continuous for over 300 miles.

The underlying Niobrara, though continuous and possessing much the same appearance varies greatly in character and chemical composition and the individual layers are not so continuous, as may be seen from three different analyses made upon rock taken from the same horizon in three widely separated places. The samples were taken from the layers of rock immediately below the first yellow layers referred to in the different sections.

	Sample No. 13 Per Cent.	Sample No. 4 Per Cent.	Sample No. 16 Per Cent.
Calcium carbonate	56.89	2.31	64.70
Silicia	17.18	67.51	14.38
Iron and alumina	9.23	20.08	7.89
Magnesium carbonate	0.79	2.55	0.34

No. 13 is from the outcrop at Mayo's Brick Plant.

No. 4 is from the outcrop on Park river.

No. 16 is from the outcrop on Pembina just south of the Canadian boundary.

PIERRE SHALE.

Conformably overlying the Niobrara is the Pierre shale, the lower member of the Montana series. The actual contact of the two formations is not easy to determine, but approximately it may

be put at the base of the remarkable series of black and yellow bands which occurs at the juncture of the two. These bands present a striking appearance where well exposed. They also have a remarkable uniformity throughout a large area, being very nearly uniform in number and thickness for a distance of thirty-five miles along the eastern border of Cavalier county and extending into Canada for an unknown distance, while their occurrence near Valley City has been reported by Mr. C. H. Clapp.

These yellow layers consist of a very fine clay-like substance, which is unctuous to the touch but has a very poor plasticity. They have a decided astringent or alum taste, and render the water of wells in which they occur unfit for use. A case of this kind was reported by Mr. W. Doner southeast of Walhalla, where a well had been dug through several feet of delta deposit and shale down to these alum shales. While these bands are yellow on the outside they invariably change to a dark blue when penetrated beyond the zone of weathering. This shows that the iron exists in a ferrous state, being oxidized to the yellow ferric form on exposure. A hand sample of the unaltered material was collected but in a few days the outside of each lump had turned yellow.

As to the origin of these yellow layers it may be said that their uniformity denotes a period of quiet and even sedimentation and probably also very slow deposition in comparison with that preceeding and following their formation. The water in which the materials settled was probably heavily laden with solutions of aluminum sulphate along with a relatively small amount of the alkalies which would form alum with the sulphate and thus serve as a precipitating agent of the fine slimes present.

Analyses of the clay forming the yellow layers indicate the following composition:

	Per cent.
Silica	49.13
Alumina	34.87
Ferric oxide	4.39
Calcium oxide	1.17
Sulphur trioxide	4.65
Alkalies and undetermined moisture	5.79

All of these constituents are soluble in hydrochloric acid except the silica, which is left behind in a powdery condition rather than in a gelatinous form. This seems to indicate that it is present either in a finely divided free state or very loosely combined with

the alumina. A considerable portion of the alumina is soluble in warm water, which indicates the presence of free aluminum sulphate or possibly alum.

As already noted, these bands preserve a very uniform character throughout a very large area in North Dakota, and they also extend at least 250 miles northwestward in Canada. Their occurrence was noted in the Cretaceous outcrops in the Riding and Duck mountains by V. J. Melsted, where they have exactly the same characteristics as in the Pembina Mountains except that they are better developed. The lowest layer noted in these northern outcrops was thirty inches thick and was overlain and underlain by a four-inch band of gritty limestone. The other bands were from four to six inches thick.

The thickness of the Pierre shale varies widely. It is greatest in the central part of the state, so far as known, and thins out toward the east. This is probably due not so much to actual thinning of the beds as to the greater erosion which the eastern portion has suffered. The total thickness left near the edge of the escarpment in no case exceeds 450 to 500 feet, while toward the west the formation attains a thickness of at least 1,000 feet.

The Pierre is a gray to black shale, rather soft and free from grit. In weathering it breaks up into many small flakes which harden when dry and remain fairly hard. It is pebbles of this shale which are so abundantly scattered through the soil of the western part of the Red River Valley and which are commonly but erroneously called slate.

The Pierre formation is quite uniform throughout with the exception of the lower forty to fifty feet in which are found many layers of clay ironstone which on the weathered exposures form well defined bands along the bluffs. This is especially well seen in the excellent exposures on the Park river half a mile north of Milton. The river here flows through a prairie region and its banks are for the most part devoid of any timber growth. The valley is deep and its sides are steep and in many places cut banks afford a clean, well exposed section from top to bottom.

The composition of the shale varies somewhat from place to place in a horizontal section but probably more from top to bottom. A typical sample was collected on the well exposed bank

of a smaller creek north of Union about a quarter mile east of where the railroad crosses the creek valley. It had the following composition:

Analysis of Pierre Shale.

	Per cent.
Silica	60.17
Alumina	17.35
Ferric oxide	4.91
Calcium oxide	2.09
Magnesia	1.78
Sulphur trioxide	0.41
Loss on ignition	10.11

In many places, where it is free from inclusions of pyrite, the shale is well suited for the manufacture of brick and is used for that purpose at various places in Manitoba. There is no reason why similar industries should not thrive here, where this shale is adjacent to suitable transportation facilities. This subject is treated more fully in another part of this report.

Upham reports that Cretaceous strata have not been found east of the foot of the highlands of the Pembina, Riding and Duck mountains, nor in the regions north and east from Lake Winnipeg to Hudson Bay.¹ It seems quite certain, however, that Cretaceous beds originally extended eastward a considerable distance, probably so far as to cover the area now occupied by Lake Winnipeg. As Hind and Dawson have pointed out, it was by the erosion of this eastern portion that this steep line of highlands was formed;² and it may be expected that thin remnants of them will yet be found in central and eastern Manitoba.

Horace V. Winchell and N. H. Winchell have noted in the reports of the Geological and Natural History Survey of Minnesota, the eastward continuation of the Cretaceous formations in southern and central Minnesota; and also to the north, on the Little Fork of Rainy river.³

It is known that before the Cretaceous period, when western Minnesota and the region of the Upper Missouri were depressed and covered by the sea, a deep channel had been cut by some river in the Lower Silurian and Cambrian strata of the Minnesota

¹Mon. XXV, U. S. G. S., p. 100 et seq.

²H. V. Hind, Report of the Assiniboine and Saskatchewan Exploring Expedition, Toronto, 1859, pp. 168, 169; Narrative of the Canadian Exploring Expedition, London, 1860, Vol. II, pp. 48, 55 and 285. G. M. Dawson, Geology and Resources of the Forty-ninth Parallel, 1873, pp. 253, 254.

³Geol. and Nat. Hist. Survey of Minnesota, Sixteenth Annual Report, for 1887, pp. 403-9, 431, 434, Geology of Minnesota, Final Report, Vols. I and II.

Valley; but the small width of this channel indicates that the stream then flowing there, probably westward, was not larger than the present Minnesota river. This and many other streams of similar size, flowing into the Cretaceous ocean as it spread to the east over the former land surface of Iowa, Minnesota and Manitoba, contributed part of the detritus which formed the vast mass of sediments, probably averaging a quarter of a mile in depth, covering most of its area. These beds could be supplied only by the extensive denudation of the land areas both west and east of the Cretaceous mediterranean sea.

The great disturbances of the region to the west during the elevation of the Cordilleran mountain ranges, since the Cretaceous period, make it impossible to trace there the course of the larger streams entering this sea. On the eastern half of the continent the principal drainage system, carrying its vast freight of detritus west to the Cretaceous ocean, is probably marked by the chain of great lakes from Ontario to Superior; the west end of which is close to the east border of the submerged belt. At that time, and onward through the Tertiary era much of this eastern land area appears to have been elevated at least three hundred feet above its present level, so that streams eroded the deep basins which are now occupied by these lakes, but which then had a continuous westward descent. It seems probable also that other great tributaries may have flowed westward and southward into the Cretaceous sea, bringing sediments eroded from the areas of Hudson Bay, Lake Athabasca, Great Slave and Great Bear lakes. Thus were accumulated in the great Cretaceous sea of the interior the thick formations of the Great Plains region.

Since their elevation above the sea erosion has been slowly but constantly wearing away the Cretaceous rocks. When these marine and lacustrine deposits were first raised to form land they had a monotonously flat surface, and they probably extended east, as we have seen, over the entire basin of the Red River of the North and the great lakes of Manitoba and west as far as the Rocky Mountains. The greater part of the present Cretaceous area, though eroded far below its original surface, is flat, undulating or moderately rolling and constitutes a broad expanse of plains with very slow ascent westward. But here and there isolated areas of much higher ground as the Turtle Mountains, consist of remnants of horizontal Cretaceous strata which elsewhere have suffered denudation. The plains

have been formed by the erosion of this vast area to a uniform base level, excepting isolated hilly tracts of comparatively small extent, which serve to show that on the eastern part of the plains, in North Dakota and southwestern Manitoba a thickness of not less than 500 to 1,000 feet of the Fox Hills and Fort Pierre formations has been carried away. But during the same time the erosion about the Highwood and Crazy Mountains was from 3,000 to 5,000 feet in the horizontally bedded Cretaceous formations.

When the depth and great extent of this denudation are compared with that of the subsequent erosion which formed the Red River Valley and the lowland adjoining the Manitoba lakes by the removal of the former eastward extension of the Cretaceous formations, the early base leveling seems probably to have occupied a large part of Tertiary time. Its duration apparently coincided with the cycle of partial base-leveling which took place in Pennsylvania and other eastern states. The termination of this denudation of the Cretaceous area, and its uplift to undergo the erosion of the Red River Valley and of the present Assiniboine and Saskatchewan valleys, were probably also contemporaneous with the great epeirogenic movement which in California according to Mr. J. S. Diller, ended a long cycle of base leveling that had extended through the whole of Cretaceous and Tertiary time, and raised a part of that base leveled district at the beginning of the Quaternary era to form the lofty Sierra Nevada¹. Again, the same record of long continued base leveling, followed by uplift and a new cycle of rapid valley erosion, is found by Powell and Dutton in the plateaus and Grand Canyon of the Colorado.² The denudation of these plateaus, when compared with the studies thus noted in other regions and with the total erosion of the canyon, seems to have required not only the Eocene and Miocene periods but also most of the Pliocene; for the ratio of the general denudation to the canyon-cutting must be nearly or quite as great as that between the duration of the entire Tertiary era and the comparatively short time since its close. Instead of referring the division of these parts of the history of the Grand Canyon district to the beginning of the Pliocene, as was done provisionally by Dutton, it may therefore mark the final stage of the Pliocene and the inaugura-

¹Eighth Annual Report U. S. Geol. Survey, pp. 428-432.

²Exploration of the Colorado River of the West, 1875. *Geology of the Eastern Portion of the Uinta mountains*, 1876. Mon. 11., U. S. Geol. Survey, 1882. *Am. Jour. Sci.* (3), Vol. XXXII, pp. 170, 171, Sept., 1886.

tion of the Glacial period, with high elevation of all the northern part of this continent and of the glaciated northwestern portion of Europe.¹

At the time of the uplifting of the Great Plains near the end of the Tertiary period this great base leveled region appears to have stretched from the Rocky Mountains to the Archean hills on the eastern border of Lake Agassiz, and to have included also the expanse of flat or only moderately undulating country which slopes gradually from Lake Winnipeg and the upper part of the Nelson river towards Hudson Bay. The Tertiary drainage of this district from the present sources of the Saskatchewan, Red and Rainy rivers to Hudson Bay and Strait, probably formed a great river flowing through the Appalachian-Laurentide mountain belt in the deep valley which is now submerged to form this strait, and emptying into the Atlantic between Labrador and Cape Farewell. The depression of the lower part of this basin seems referable to the time of the culmination and departure of the Quaternary ice-sheet. Between the Tertiary base leveling and this subsidence a widely extended epeirogenic uplift of North Dakota intervened. To this period of late Pliocene and early Quaternary elevation belong the erosion of the canyons of the Colorado and its tributaries, of the canyons on the slopes of the Sierra Nevada, and much river channeling of the plain east of the Rocky Mountains.

The eastern margin of these plains, which probably extended, as before stated, over the whole area of Lake Agassiz, was then subjected to renewed erosion, removing the soft Cretaceous strata over a width of a hundred miles or more and to a depth toward the west of several hundred feet. Previous to this new cycle of active work by the streams, Riding and Duck mountains stood above the general level, like the Turtle Mountains and other isolated higher areas farther west, and the maximum depth of the late stream-cutting by which the trough of the Red River Valley and Lake Agassiz was formed is approximately measured by the height of the Pembina Mountain escarpment, which rises 300 to 400 feet from its base to its crest throughout an extent of about eighty miles. The greater part of this erosion we must attribute to the probably long time of elevation preceding, and finally at the climax producing, the ice-sheet of the Glacial Period. So far as can be discerned, the entire

¹Ann. Geol., Vol. VI., pp. 327-339, 396, Dec., 1890. Am. Jour. Sci. (3), Vol. XLI, pp. 33-52, Jan., 1891; Vol. XLVI, pp. 114-121, Aug., 1893.

hydrographic basin of Lake Agassiz may have continued, through all these changes of level, excepting when ice-covered, to be drained in the same north and northeast direction as during the Tertiary era and at the present day.¹

In the progress of denudation by Tertiary base leveling and by the later erosion of the depression which was to hold Lake Agassiz, some of the Cretaceous strata have proved more durable than those next above and below, and consequently have had a more important influence on the topography. This is especially noteworthy in the case of the Fort Pierre formation, which forms the upper and main part of the great escarpment that borders the west side of the Lake Agassiz basin from the Coteau des Prairies north-northwest to the Saskatchewan river. East of the Red River Valley in Minnesota the similar but less prominent ascent from the flat valley plain doubtless also consists of Cretaceous shales, perhaps chiefly the Niobrara and Fort Benton formations, beneath the envelope of glacial drift. Farther east and southeast, through northern and central Minnesota, it seems certain that at least many knolls and hills thus far had escaped the general Tertiary and early Pleistocene denudation, but most of them were leveled during the Ice Age and mingled with the glacial drift. Westward from the Pembina and Manitoba escarpment the Fort Pierre formation generally constituted the preglacial surface, and is now the floor on which the drift lies.

The source of the preglacial rivers flowing from the Cretaceous area west of Lake Agassiz, after the late Pliocene uplifting of the continent, probably coincided approximately with the present drainage lines throughout the region north of the international boundary, in the Assiniboine, Saskatchewan and Athabasca basins. In North and South Dakota, the present channel of the Missouri river, as shown by General G. K. Warren² and by Prof. J. E. Todd, dates only from the Glacial Period, this great stream having apparently been turned to the west and south by the ice-sheet. Its preglacial course may have occupied the valley of the James river, nearly parallel with the Missouri of today, or perhaps it continued east to the most southern bend of the Souris river, or to the Sheyenne and Red rivers. Professor Todd finds also in the topography of that region evidence that in preglacial time the great tributaries coming from the west

¹Am. Geol., Vol. XIV, pp. 235-246, Oct., 1894. Bull. Geol. Soc. Am., Vol. VI, pp. 17-20, Nov., 1894.

²Ann. Report, Chief of Engrs., U. S. A., for 1868, pp. 307-314.

to join the Missouri, namely, the Cannon Ball river, the Grand and the Moreau rivers, then united, the Sheyenne, and the White rivers, flowed east to the valley of the James; and he is inclined to believe that from that valley the great stream formed by these affluents passed northeast to the Red River of the North and Hudson Bay.¹ That the greater part of the excavation of the trough of Lake Agassiz could be accomplished by a river of such size during the Lafayette period of continental elevation, following the Pliocene period and inaugurating the Ice Age, may be readily believed when we compare it with the Lafayette erosion of the Mississippi, which from Cairo southward along an extent of about 500 miles, formed a channel 200 to 300 feet deep and averaging sixty miles wide.²

Tertiary and early Quaternary erosion had sculptured the grand features of the basin of Lake Agassiz, and its whole extent probably had approximately the same contour immediately before the accumulation of the ice-sheet as at the present time. The surface of the feldspathic Archean rocks was doubtless in many places decomposed and kaolinized as is now seen in regions that have not been glaciated, where the rocks are frequently changed to a considerable depth. On these and all the other rock formations the ordinary disintegrating and eroding agencies of rain and frost had been acting through long ages. Much of the loose material thus supplied had been carried by streams to the sea, but also remained and was spread in general with considerable evenness over the surface, collecting to the greatest depth in valleys, while on ridges or hilltops it would be thin or entirely washed away. Except where it had been transported in part by streams and consequently formed stratified deposits, the only fragments of rock held in this mass would be from underlying or adjoining beds. The surface then probably had more small inequalities than now, due to the irregular action of the processes of weathering and denudation which are apt to spare here and there isolated cliffs, ridges and hillocks; but most of these minor features have been obliterated by glacial erosion or buried under the thick mantle of drift.

The character of the Pierre shale is well shown in the following sections which were measured at a number of outcrops, beginning at the south and going north.

¹Proc. Am. Assoc. Adv. Sci., Vol. XXXIII, 1884, pp. 381-393, with map.

²Am. Naturalist, Vol. XXVIII, pp. 979-988, Dec., 1894. Bull. Geol. Soc. Amer., Vol. V, 1894, pp. 87-100.

The South Branch of the Park river flows through a treeless region and even the valley itself is very lightly timbered. It thus provides a very good field for the study of the different outcrops which occur along its banks. In no place has it cut through the Pierre down to the underlying Niobrara, but there are numerous very fine exposures of the Pierre. A typical section taken about a mile and a half above where it merges from the escarpment is as follows:

- Feet. Inches.
4. Glacial drift, varying greatly in thickness. In places it is practically nothing, the soil consisting of shale weathered in situ; in other places it is thick, up to 25 or 30 feet. It consists of a yellowish clay containing boulders of igneous rock in varying amounts, but very seldom being entirely free from them. Fragments of unweathered shale are very rare, in which respect the drift here differs greatly from that farther north, where shale is a very common constituent, even in places furnishing the bulk of the drift.

3. Shale, dark and uniform in character, varying in thickness from a few to a hundred feet. It is darker than the underlying shale and contains no concretions; is fissile and weathers easily. The weathered product is a black, very sticky clay. In places it is quite alkaline10-100

2. Shale, medium dark and fissile, and interspersed with numerous horizontal bands resembling clay ironstone, varying from an inch up to a foot in thickness. These are more resistant to erosion than the shale and thus form a very striking feature of some of the outcrops, as they form little ledges or shelf-like projections which give the exposure a horizontally banded appearance. The shale is very fissile but quite compact and hard and does not weather readily. It is from this formation that most of the so-called "slate," which characterizes the soil of the Red River Valley in many places, is derived150

1. Shale, carbonaceous, very dark and uniform. It has well developed cleavage, but is not very fissile, and weathers to a brownish plastic clay 30

A sample of shale taken near the waters edge showed the following composition:

	Per cent.
Silicia	75.37
Alumina	11.25
Ferrie iron	3.75
Lime	2.98
Magnesia	3.15
Sulphur trioxide	0.58

The sample was weathered but was stained slightly yellow along the seams, undoubtedly due to a small amount of ferrous oxide. It showed no sand on casual examination but a small per cent was revealed upon washing the dried sample.

A sample taken near the top of No. 3 of the section just mentioned showed the following composition:

	Per cent.
Silica	66.09
Alumina	8.31
Ferric oxide	3.92
Lime	1.47
Magnesia	2.81
Sulphur trioxide .....	.53
Alkalies combined	2.13

This sample was free from sand and very fine and compact. It represents a typical sample from near the top of the Pierre and it is from shale of this composition that the black "gumbo" soil is produced.

Going north the next locality where the Pierre is well exposed is a short distance south of Union, where a small creek has cut a narrow V-shaped valley. There are several good outcrops along this stream. The following section occurring on the southeast quarter of section 25, T. 159, R. 57, is probably the best exposed.

	Feet. Inches.
4. Glacial drift, yellow, and composed of rather sandy clay with large boulders. In places it rests directly on No. 3, but in others there is a layer of shale above No. 3, similar to No. 2.....	10-15
3. Pyritic concretions, which near the surface are altered to limonite. These are very hard and resemble those found in the horizontal bands previously mentioned on the South Branch of Park river..	1
2. Shale, medium dark, very fissile and all joints highly stained with iron	20
1. Shale, dark, carbonaceous, breaking into rather large conchoidal fragments; has many cracks slightly stained with iron	4

North of Union, where the Great Northern Railway crosses a deep ravine, there is a very good outcrop on the northeast quarter of section 26, T. 159, R. 57, as shown in the following section:

	Feet. Inches.
8. Drift and soil	10
7. Shale, similar to No. 5	10
6. Concretionary nodules and shale highly stained by iron	1
5. Shale, grayish, very fissile	18
4. Concretions, similar to No. 2	3
3. Clay layer, dark yellowish; very soft and plastic, free from sand and grit. Shows joints and seams	

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- | | |
|---|---|
| similar to shale but does not resemble clay which
has resulted from alteration of shale | 1 |
| 2. Concretions, very hard and compact layer. Appears
to be shale very highly impregnated with iron.. | 2 |
| 1. Shale, very similar to No. 1 in the previous section | 6 |

A very peculiar feature of this outcrop and one not found elsewhere in the Pierre formation is the one-foot layer of yellow clay, No. 3. It was easily traced for a mile along the side of the ravine and preserved the same thickness and general characteristics throughout that distance. It can hardly be referred to as an alteration product of the shale as it is overlain and underlain by unaltered shale. It is possible that it is a stratum which has been the source of springs of water percolating between the two different layers of shale, but more likely it is a small separate layer of the Pierre shale which originally differed from the rest in composition and character. It occurs between strata which differ radically in essential features and it may thus represent a transitional stage.

On the North Branch of Park river where it cuts through sections 4, 5, and 9, of T. 159, R. 57, there are numerous fine exposures of Pierre. The gorge is here deeper than at any other place along the river's course, and from a quarter to a half mile wide. A description by Warren Upham of an outcrop in this gorge will give a good idea of the lower part of the Pierre as it is exposed east of Milton.

"In these places the stream flowing at the base of the bluff removes the talus which in other places conceals its lower portion, and the section rises with cliff-like abruptness at an angle of sixty to seventy degrees.

"Excepting occasional thin beds the whole thickness of the section here exposed is a gray hard shale more or less sandy, divided into layers from an eighth of an inch to two or three inches thick, and much jointed as it crumbles down into small fragments on the weathered surface. Rarely a bed a few inches thick, having the general dull color, is harder and less jointed, owing to its cementation by carbonate of lime, and occasionally the ordinary shale is blackened by the deposition of iron rust and manganese oxide as films in the jointage seams, the thickness of the portions thus colored being usually only a few inches, but in one instance half way up the north bluff three or four feet. Gypsum was observed only

in minute crystals in fissures coinciding with the beds of stratification; and in the form of satin spar filling the mold from which some shell, usually *Inoceramus*, has been dissolved away."

"Fossils are very infrequent but by careful search *Baculites ovatus* and *Scaphites nodosus* Owen were found, each represented by a single specimen; also numerous *Inoceramus* casts, mostly *Inoceramus sagensis* Owen, besides casts and fragments of other lamellibranchs, not yet identified; and the teeth of fishes, apparently *Pachyrhizodus latimentum* Cope and *Lamna mudgei* Cope, a smaller species. The teeth occur somewhat plentifully in a remarkably hard layer, six inches to a foot thick, about fifty feet above the stream. With them this layer contains softer lumps of somewhat irregular shape from one third to three quarters of an inch in diameter of a light gray color inside with a greenish exterior, which are probably coprolites. The other fossils were found in the shale fragments forming the talus and their place in the section was not determined."¹

The harder layers referred to above correspond to what have been termed concretions in the previous paragraphs. They really are only shale indurated with iron, but the layers are jointed in such manner that the loose blocks resemble regular concretions in shape. Neither is this the result of metamorphic changes in the shale itself but has its origin with the deposition of the shale. The so-called "coprolites" above referred to were determined to be altered pyrite concretions. On weathering the somewhat impure pyrite had altered to copiapite.

Further up stream, north and northeast of the town of Milton, there are some fine Pierre shale outcrops differing in no essential respects from the ones already described. They are well shown from the wagon road north of Milton where it passes along side of and crosses the gorge of the North Branch of the Park river.

For a distance of three or four miles north of the point where the above mentioned branch of the Park river leaves the Pembina escarpment, there are no natural outcrops of either Pierre or Niobrara. The escarpment here seems to be relatively low. Nearly the entire Pierre has been eroded and in several places well sections reveal the drift lying directly on the Niobrara, which is quite fresh and unaltered immediately in contact with the drift. The

¹Monograph XXV, U. S. Geol. Survey, pp. 93.

comparatively recent deposition of the drift has prevented alteration of the freshly glaciated surface of the underlying shale. As one passes westward from the edge of the escarpment the surface rises gradually and the Pierre formation is well developed. It thus appears that the absence of the Pierre on this restricted area is due to abnormal glacial or preglacial erosion rather than to a thinning out of the beds. The cause of this undue erosion of the Pierre may perhaps be due to a slight anticline in the Cretaceous strata which here seems to reach its maximum, thus rendering the strata peculiarly susceptible to erosion, especially glacial erosion.

An outcrop of Pierre in the southeast quarter of section 36, T. 160, R. 57, shows the following section:

	Feet.	Inches.
5. Glacial drift	30	
4. Shale, similar to No. 2	10	
3. Yellow band, similar to those in No. 2, and to layers occurring on the North Branch of Park river		2
2. Shale, gray, stained a bright yellow in fissures and containing numerous selenite crystals. This yellow stain in numerous places had formed thick hard crusts resembling impure sulphur, and is regarded as such by many, but when tested it yielded all the reactions of earthy limonite.....	25	
1. Clay bands, alternating black and yellow.....	5	

This outcrop is on the north bank of a small stream which at this place has cut quite a wide valley. But half a mile further up there is only a narrow V-shaped gorge, while two miles above it has dwindled down to a flat, imperfectly drained marsh. This seems to be the general condition of all the smaller streams which leave the escarpment. For a short distance from the escarpment they have large wide valleys rivaling those of the Tongue and Pembina rivers in depth and width, but they extend only two or three miles back into the upland plain, while the valleys of the Tongue and Pembina extend nearly undiminished in size to within a few miles of their source.

PLEISTOCENE.

During the latest geological period, immediately preceding the Recent, or present period in which we live, the north part of our continent was deeply enveloped in snow and ice. Every year the snowfall was greater than could be melted away in the summer, and its depth gradually increased until its lower portion was changed to compact ice by the pressure due to the weight of the

overlying mass. This pressure also caused the vast sheet of ice to move slowly outward from the region of its greatest thickness toward its margin.

Among the proofs of the Glacial Period, it is first to be observed that the surface of the bed-rock in the northern drift-covered portion of North America bears parallel scratches and markings, called striae, like those which are found beneath the glaciers of the Alps. Only one cause is known which can produce markings like these and that is the rasping of stones and boulders frozen in the bottom of the moving mass of ice accumulated upon the land in a solid sheet of great extent and depth. As these striae are found upon the rocky surface of British America and our own country to a southern limit that coincides approximately with the course of the Ohio and Missouri rivers, we must conclude that an ice-sheet has covered these regions.

The superficial material that overlies the bed-rock within the northern glaciated area has been plowed up and worked over by the slowly moving ice-sheet, and at its disappearance the greater part of this glacial drift was left as a deposit of clay, sand, gravel and boulders, mixed in a confused mass which is called till. The thickness of the till upon much of the bed of Lake Agassiz is from 50 to 200 feet, but in some tracts it is only five, ten, twenty or thirty feet. Throughout nearly all of this lacustrine area lying in Minnesota and North Dakota it forms a sheet of such great extent and thickness that exposures of the underlying older rocks are very rare or wholly absent, none being known in the Minnesota portion of the basin of the Red river.

By the directions in which the boulders have been carried from their original ledges, and by the courses of the glacial striae, it is known that the ice moved in general from north to south. In the region of the Great Lakes and westward to the Rocky Mountains, the ice-flow was mostly to the southwest and south. In western Minnesota and eastern North Dakota the ice flowed southward from Lake Winnipeg to Big Stone lake, and thence southeast into northern Iowa, spreading a blue till, with many limestone boulders derived from outcrops of Silurian limestone strata near Winnipeg.

Besides the striae, till, and transportation of boulders, another proof that the drift was formed by vast sheets of land ice is sup-

plied by terminal moraines, or hills, knolls and ridges of drift heaped along a line representing a stationary period of the ice border. These moraines are found stretching in remarkably curved and looped courses across the northern states from Nantucket and Cape Cod to North Dakota. The outermost one bounds the areas that were overspread by the ice-sheet during the latter part of the Glacial Period, which has been named the early Wisconsin stage;¹ and others mark the lines where the ice border paused or readvanced during its subsequent general recession.

The portion of North America and outlying islands which were covered by the ice-sheet and are now overspread with drift have an area of 4,000,000 square miles. The thickness of the ice-sheet, known by the limits of glaciation on mountains, increased from a few hundred feet in the vicinity of its border to about one mile at a distance of 200 to 250 miles inside the border, both in New England and British Columbia; and from these data and from the courses of glacial movement and distribution of the drift, it is computed to have ranged from one to two miles or more in its central portions. Probably two-thirds of a mile, or about 3,500 feet, is a fair estimate of the average thickness, or the mean depth of the ice-sheet at its stage of maximum development. In its recession the ice became the northern barrier of Lake Agassiz, and its immense mass probably exercised a great influence in producing changes in the relative levels of the land, the lakes and the sea.

The prevailing courses of glaciation and dispersal of the drift have led geologists to recognize the existence of three central areas upon which the ice was accumulated in greater depth than elsewhere, and from which consequently it flowed outward on all sides. At the time of greatest expansion the ice-sheets covered nearly all of north America down to forty degrees north latitude. Three distinct centres or areas of maximum accumulation of the ice have been identified in northern Canada, from which the great ice-sheets flowed outward in all directions, though each one of the sheets had its own episodes of advance and retreat, so that the same region of country was overflowed, now by extensions from one sheet, and again by those from another. One of these centres of accumulation and distribution lay to the north of the St. Lawrence river, on the

¹"Preliminary paper on the terminal moraine of the Second Glacial Epoch," by T. C. Chamberlin, in the Third Annual Report, U. S. Geol. Survey, pp. 291-402.

"Glacial phenomena of North America," forming two chapters in J. Geikie's *Great Ice age*, third edition, 1894, pp. 724-775, with maps.

highlands of Labrador, sending its ice mantle southward over the Maritime Provinces, New England and the Middle States, as far west as the Mississippi river. This is called the Laurentide, or Labradorean ice-sheet or glacier. A second centre was near the west coast of Hudson Bay, and from this area the ice streamed outward in all directions, westward to the Rocky Mountains, northward to the Arctic Ocean, eastward into Hudson Bay, southward through Manitoba into the Dakotas, Minnesota and Iowa. This grand ice-sheet has been named the Keewatin glacier, from the Canadian district of that name. A third centre was formed by the Rocky Mountains of British Columbia, which for a distance of 1,200 miles was buried under a great ice-mantle that flowed both to the northwestward and southwestward.

An ice-sheet similar to that of North America in the Glacial Period now covers the Antarctic lands, and another is spread over the interior of Greenland. The latter has been so far explored that its slopes and altitudes may be compared with the ancient ice-sheets of North America and Europe. In comparing the slopes and altitudes of the upper limits of glaciation on mountains in Maine, New Hampshire and New York, with those in Greenland, we observe the remarkable contrast that the former show gradients only about half as steep as the latter. Apparently the conditions for outflow of the ice in the case of Greenland are similar and equally favorable with those which prevailed on our continent in the Glacial Period. The comparison therefore suggests that the present elevation of the glaciated portion of this continent is probably much changed from that which it had during its epochs of glaciation. If the North American ice-sheet during its stages of growth and culmination attained steep slopes and high altitudes near its borders comparable with the Greenland ice, the records of glaciation on our mountains show that during the time of accumulation of the ice and until it attained its maximum extent the glaciated area was uplifted as a high continental plateau, with the same principal topographic features of mountains, valleys and general contour as in preglacial and post-glacial times, but having in its outer 100 or 200 miles slopes of probably twenty to thirty feet per mile, descending from the plateau of the interior of the ice-enveloped country to its margin.¹ Similar uplifting seems also to have affected the glaciated northwestern part of Europe, for there, too,

¹The Ice Age in North America, p. 595.

the slopes and heights of the limits of the drift resemble those of North America rather than the Greenland ice-sheet.

At the end of the Glacial Period, however, the glaciated regions are known to have been depressed somewhat below their present level. This change seems to have been well accounted for by the vast weight of the ice-sheet itself, causing the land to sink finally beneath its load and the subsequent rise of the land is an expression of the bouyancy of the earth's crust when it had been relieved by the disappearance of the ice. The preglacial elevation may well have had some effect in producing a cool climate throughout the year, with abundant snowfall and resultant ice accumulation; and the subsidence of the burdened land would cause rapid melting of the ice upon its borders and thence backward progressively over its whole area.

During the departure of the ice its melting was due to the influence of sunshine and rains, the latter being doubtless brought then, as now, by great storms sweeping across the continent in a northeastward course. In consequence, the borders of the ice-sheet appear to have been pushed back generally in the same northeastward direction, beginning on the west in the region of the Missouri and upper Mississippi rivers and of the Red River of the North, and uncovering successively or almost contemporaneously the region of the Laurentian Lakes, New England, and the eastern province of Canada. Thus Lake Agassiz was formed in the Red River Valley, and the basins of the Laurentian Lakes became filled by glacial lakes outflowing southwestward to the Mississippi, until the outlet from Lake Ontario by the Mohawk and Hudson rivers was uncovered from the ice.

Extensive beds of gravel, sand and clay or fine silt, called stratified or modified drift, were deposited along the avenues of drainage from the glacial boundary, especially during its rapid final recession. The melting of the ice, with accompanying rains, produced extraordinary floods along all the rivers flowing away from the waning ice-sheet; and these were heavily laden with detritus set free from the lower part of the ice in which it had been held, and brought down by the rills and small and large streams formed on the melting ice surface.

This closing stage of the Glacial Period was immediately succeeded by a time of great erosion of the valley deposits of stratified drift, as soon as the continued glacial recession beyond the

drainage areas of the rivers cut off the supply of water and of drift that had been derived from the melting ice. The resulting excavation of the glacial flood-plains has left remnants of those deposits in conspicuous terraces along all our river valleys which lead southward within the glaciated region or on its southern border.

The direction of the currents of the ice-sheet are shown by the furrows and striae which boulders and gravel frozen in the base of the moving ice engraved upon the bed rock over which they passed. From these lines of movement the areas of its thickest accumulation and consequent outflow are known. In some districts, also, changes in the outlines of the ice border and in its slopes and currents during its final retreat are indicated by deflected glacial striae which run across the earlier courses. The southwestward striation in northeastern Minnesota and the southeastward striation in the central and southern part of that state belong to two convergently flowing lobes of the ice-sheet. The central line of the western of these ice-lobes coincided nearly with the Red and Minnesota rivers. This may be named the Minnesota lobe of the ice-sheet. Farther west the Dakota lobe stretched from the Souris basin and the region of the Turtle Mountains south across the east half of North and South Dakota to Yankton, its central line being along the valley of the James river.

On the east Lake Agassiz appears to have been bounded by a vast ice-lobe outflowing from the region of Lake Superior and James Bay southwest and south to the Lake of the Woods and Lake Itasca, representing the earlier convergent lobes of the northeastern and of the western and southern portions of Minnesota, while on the west it was bounded by the representative of the Dakota ice-lobe, then flowing out from the region of Lake Manitoba and Riding Mountain southward.

The greater part of the drift is derived from points a few miles to twenty to fifty miles away, in the direction from which the ice-sheet moved; but mingled with this material from comparatively near sources are other portions, fine and coarse, and boulders, which have been transported longer distances. The least distance from the most western of the Archean boulders to the margin of the Archean belt is about 550 miles.

A glacial lake is a body of water bounded wholly or in part by land ice. The very abundant and extensive development of glac-

ial lakes which attended the recession of the ice-sheet in the northern United States and in Canada, was due to the temporary damming of the waters of glacial melting and rains on areas where the land has a northward descent. While the ice-sheet was melting away from south to north on such a slope free drainage was prevented, and a lake was formed, overflowing across the lowest point of what is now the southern watershed of the basin. Many of these lakes were of small extent and short duration, being soon merged into larger glacial lakes by the continued retreat of the ice, or permitted to flow away where basins sloping northward are tributary to main river courses draining southward.

Five principal evidences of the former existence of glacial lakes are found, namely: 1. Their channels of outlet over the present watersheds. 2. Cliffs eroded along some portions of the shores by the lake waves. 3. Beach ridges of gravel and sand, often, in the larger glacial lakes extending continuously for long distances. 4. Delta deposits, mostly gravel and sand, formed by inflowing streams. 5. Fine sediments spread widely over the lacustrial area. Lake Agassiz has left all these marks of its presence.

The five or six distinct beaches that were formed at the southern end of Lake Agassiz during its outflow southward are represented in the northern part by seventeen separate shore-lines, which are marked by definite beach ridges. The individual beaches at the south, when traced northward, become double or triple, and the highest or Herman beach expands into seven successive shore-lines. The explanation of these changes of level is found in a differential uplifting of the lake basin, increasing in amount from south to north.

The departure of the ice-sheets which spread the drift formations over the northern part of North America, northwestern Europe, and Patagonia, was in each of these great and widely separated areas attended by a depression of the land. While each of these ice-sheets was melting away, the land which they covered was somewhat lower than now, and its coasts were partially submerged by the sea. These are the only extensive regions of the earth which have lately borne ice-sheets that have now melted, and it seems to be a reasonable inference that the vast weight of their burdens of ice was an important element in causing their subsidence. Since

the disappearance of their ice-sheets, each of these continental areas has been uplifted, probably in large measure because of the withdrawal of the ice-load.

Though Lake Agassiz attained vast areal extent, its duration or extent in time was geologically brief, as is shown by the small volume of its beach deposits and lacustrine sediments in comparison with the Pleistocene lakes of the Great Basin and with the amount of post-glacial erosion and deposition on the shores of the great lakes tributary to the St. Lawrence and Nelson rivers. It is variously estimated that from 6,000 to 8,000 years have elapsed since the recession of the ice-sheet. When the bed of Lake Agassiz was gradually uncovered from the water of the receding lake, some parts of its central plain, through which the Red river flows, probably remained as broad, shallow basins of water, which have since been filled with fine clayey alluvium from the river and its tributaries.

Deposits left by the ice-sheets are present throughout the whole area under discussion. In the Red River Valley they underlie the lacustrine clays and silts. The beach deposits of gravel and sand due to wave action on the shores of Lake Agassiz have already been discussed under topography. West of the Red River Valley the glacial deposits are found everywhere, and the underlying formations are exposed only where the stream cutting has penetrated through the drift.

The loose superficial material provided by preglacial weathering and stream erosion was generally plowed up and removed by the ice-sheet, being carried forward in the direction of its motion and mingled with other materials similarly gathered along the path of the ice-sheet. Besides the gravel and finer alluvial detritus of valleys and a mantle of residuary clay, more or less enveloping all the country, occasional boulders and rock masses were supplied on the higher lands by the irregular action of the preglacial denudation, ready to be borne along and deposited in the glacial drift. But the ice-sheet commonly did more than remove the loose material previously existing, as is shown by rock surfaces embossed, planed and striated by glacial erosion. In general, far the greater part of the drift was thus torn off, and most of its boulders were torn and plucked away from the rock over which the ice-sheet moved, grinding it with the drift material contained in its basal portion under the pressure of the enormous weight of thousands of feet of ice.

It should be added, however, that the depth of the glacial erosion was probably nowhere so great as to change the principal and grander topographic features of the preglacial contour. The most important influence of glacial action upon the topography was usually the removal or partial wearing away of comparatively small projecting knobs, and the filling up of depressions and valleys, bringing the surface to a more uniform contour than before the ice invasion.

The thickness of the sheet of superficial deposits overlying the bed-rock upon the area of Lake Agassiz is shown by wells to vary from about 125 feet to 260 feet or more in Minnesota, commonly from 200 to 300 feet in North Dakota, and from 50 feet or less to 250 feet or more in Manitoba. Wells in North Dakota pass into the strata underlying the drift at the depth of 220 feet in Fargo, 250 feet in Casselton, 310 feet near Grandin and Kelso, and 298 feet at Grafton.

Till or boulder clay constitutes the greater part of the entire sheet of superficial deposits resting on the bed-rock, both within the area of Lake Agassiz and upon the adjoining country. But in some places this unmodified glacial drift is covered by modified drift or the stratified gravel, sand and clay deposited by streams which flowed from the ice during its melting, or by lacustrine and fluvial sediments. Fully half of the area of Lake Agassiz in Minnesota and North Dakota has a surface of till. Beneath the delta deposits of gravel and sand, and along the central portion of the Red River Valley, where the surface is commonly fine silt or clay, a sheet of till lies between these sediments and the bed-rock.

The till is the direct deposit of the ice-sheet, as is shown by its consisting of clay, sand, gravel and boulders, mingled indiscriminately in an unstratified mass, without assortment or transportation by water. Very finely pulverized rock, forming a stiff, compact, unctuous clay, is its principal ingredient, whether at great depths or at the surface. It has a dark, bluish-gray color, excepting in its upper portion, which is yellowish to a depth that varies from five to fifty feet, but most commonly between fifteen and thirty feet. This difference of color is due to the influence of air and water upon the iron contained in this deposit, changing it in the upper part of the till from protoxide combinations to hydrous sesquioxide. Another important difference in the till is that its upper portion is commonly softer and easily dug, while below there

is a sudden change to a hard and compact deposit, which must be picked and is far more expensive in excavating. The probable cause of this difference in hardness was the pressure of the vast weight of the ice-sheet upon the subglacial till, while the upper part of the till was contained in the ice and dropped loosely at its melting. Upon each side of Lake Agassiz the till has a moderately undulating and rolling surface. Within the area that was covered by this lake it has a much smoother and more even contour, and in its upper portion, owing to its manner of deposition in this body of water, sometimes shows an imperfect stratification, with a scantier intermixture of boulders and gravel. Yet even where it has distinct lamination it is usually more like till than like ordinary modified drift, and contains stones and gravel through its entire mass.

The chief characters of the englacial upper portion of the till, as compared with the subglacial lower portion, are its looser texture, its more plentiful and larger boulders and smaller rock fragments, whereas they are mostly worn smooth by glaciation in the lower till, and the usually more gravelly and sandy and less clayey composition of the englacial till, owing to the washing away of much of its finer material by superficial drainage. To these originally inherent characters we must add the very noticeable post-glacial change of color of the upper till already mentioned. This change has generally extended through the englacial till, stopping at the more impervious subglacial deposit. Between the two there is also frequently a layer of subglacial stratified gravel and sand, from a few inches to several feet thick. The extremes of thickness of the englacial till appear to range from almost nothing or only a few feet for minima, to forty feet or more for its maxima near massive terminal moraines and where great currents of the ice-sheet converged.¹

Rock fragments and other drift enclosed in the ice at a considerable height above the ground were borne forward without attrition. The higher part of the englacial drift is thought by Warren Upham to have supplied most of the material forming the terminal moraines, which, therefore, have a remarkable profusion of boulders and angular gravel. When the ice-sheet was finally melted, its inclosed boulders were dropped, and they now lie frequently as conspic-

¹Bull. G. S. A., Vol. III, pp. 134-148. Am. Geol., Vol. VIII, pp. 376-395, Dec., 1891.

uous objects on both the lower and higher parts of the land. Scattered here and there in solitude on an expanse of prairie, or perched on the sides and tops of hills and mountains, they at first suggest transportation and stranding by icebergs or floe ice.

Boulders are frequent or plentiful in the till throughout the area of Lake Agassiz, their abundance being nearly the same as in the least rocky parts of the till of New England, New York, and the country surrounding the Laurentian lakes. Their usual range in size extends up to a diameter of four or five feet; but in a few localities, especially in the course of morainic belts, they were observed of all sizes up to ten or twelve feet in diameter. Generally as large a proportion as ninety-nine per cent of the boulders exceeding one foot in diameter consists of Archean granite, gneiss and schists, being derived from the Archean area on the northeast and north. With these are occasional limestone blocks, derived from the belt of Paleozoic limestones, constituting on the average perhaps nearly one per cent of the large rock fragments of the drift. The bedded and jointed character of the limestones has prevented their supplying many large boulders in comparison with the more massive crystalline Archean rocks, yet usually about half of the smaller cobbles and pebbles in the till and gravel and sand deposits are from these Paleozoic limestones. Upon the Cretaceous area a considerable proportion of the gravel and cobbles is derived from the Pierre shale but this formation supplies no large blocks.

Of the twelve moraines noted by Warren Upham, the Ninth or Leaf Hills moraine is most important in this district. On the area of Lake Agassiz the course of the ice front forming its northern border at the time of the Leaf Hills moraine probably extended westward from the vicinity of Maple Lake to Beltrami, the Goose Rapids of the Red river, Buxton and Reynolds, and thence curved northwestward, passing near Arvilla, Larimore and McCanna, to the morainic islands in the west edge of Lake Agassiz, forming the east side of the Elk and Golden valleys. In crossing the central part of the Red River Valley, the surface is till, containing plentiful small boulders and gravel, and having slight inequalities of contour, the small ridges and swells being five to eight or ten feet above adjoining depressions, remarkably in contrast with the very flat surface of lacustrine and chiefly alluvial clay and fine silt, containing no gravel or boulders, which elsewhere is the axial lowest portion of this valley plain, continuous, excepting on this belt,

from Breckenridge and McCauleyville to Winnipeg, with widths on each side of the river varying from a few miles to fifteen or twenty miles. Where the Red river has cut through this accumulation of till it forms Goose Rapids.

In North Dakota the ice barrier of Lake Agassiz during the accumulation of the Leaf Hills moraine is believed to have curved to the northwest, extending upon the area of till along the eastern side of the sand and silt delta which reaches from McCanna thirty-five miles south to Portland. The existence of this large delta, evidently due to drainage from the melting ice-sheet without dependence on the aid of any of the present streams, having been deposited by a glacial river flowing southward from the Elk Valley, implies that north of it the ice front was deeply incised. The re-entrant angle probably moved gradually toward the north from near Hatton to Larimore and McCanna and along the whole extent of the Elk and Golden Valleys, and the ice-lobes stretched southward on each side of the delta, but were like the angle, slowly undergoing change in their position by a steady or mostly intermittent recession from south to north.

The islands of morainic till which rose above the surface of Lake Agassiz at its highest stage along a distance of more than thirty miles east of the Elk and Golden valleys, between McCanna and Edinburg, were accumulated during this time on the west margin of the Minnesota ice-lobe. Their material and that of the beach ridges formed from their erosion were derived from the north and northeast, and contain scarcely any Cretaceous shale from the Pembina Mountain area. No glacial currents coming from even a few degrees west of north seem to have contributed immediately to the formation of this moraine, although during earlier stages of the glaciation currents from the north-northwest mingled their drift with that from the northeast upon this region.

Recessional morainic accumulations of till and boulders were dropped on the western side of the Minnesota ice-lobe during its retreat across the Red River Valley, where it was rapidly melted back by the laving action of Lake Agassiz, between the chief stages of formation of the ninth and tenth or Leaf Hills and Itasca moraines. In this class may belong the remarkable profusion of boulders found at a few points in Gilby township, (T. 153, R. 53), one of which is commonly called "The Island." Among other note-

worthy localities of plentiful boulders, the shores and bed of the Salt Lake of Park River, in section 36, Martin township, (T. 158, R. 52), should be mentioned, from which a belt of occasional boulders in the lacustrine silt extends northward to the vicinity of Glasston.

The ice front forming the northern boundary of Lake Agassiz at the time of accumulation of the Itasca moraine probably passed not far west of Red and Roseau lakes to the vicinity of Winnipeg. Turning southwestward it seems to have reached across the lake area to the boulder strewn escarpment of the Pembina Mountain east of Thorn Hill, and beyond to have passed south along the west shore of Lake Agassiz into North Dakota. The Itasca moraine seems to be marked by tracts of notably rolling and hilly surface from one to six miles in width, such as are crossed to the number of two or three in a journey from Milton, Osnabrock or Langdon southwest to Devils Lake. These morainic belts trend mainly from southeast to northwest, and were apparently accumulated on the southwestern border of the ice-sheet during slight pauses of its retreat.

The southern border of the ice-sheet at the time of the accumulation of moraines later than this lay to the north of the area under consideration.

In that portion of the area west of the Pembina escarpment the rolling prairie with gradual westward ascent is composed almost wholly of glacial drift or till. Only those areas which seemed to possess distinctive terminal morainic characters were mapped as such. This differs considerably from the description given by Upham, in which deposits have been mapped as continuous bands. It was found impossible to consider much of the extent of these bands as terminal moraine deposits.

ECONOMIC GEOLOGY.

The important natural resources of northeastern North Dakota include cement rock, brick shales and clays, sand, gravel, boulders and well waters.

CEMENT ROCK.

Work in mapping the outcrops of Cretaceous beds in the Pembina Mountains was carried on in the field seasons of 1907 and 1908, the work being largely of a preliminary character. A con-

siderable number of samples of the calcareous Niobrara shale have been collected and analyzed, and show the general characteristics of the beds.

The cement rock of the Pembina Mountains was discovered some years ago by Professor E. J. Babcock, who subsequently became interested with several others in the establishment of a cement mill on the Tongue river. The product manufactured is a natural hydraulic cement which has found a ready market, but the industry has until recently been seriously hampered by the location of the plant so far from any railroad. Then, too, there are no limestone deposits near at hand, so that a true Portland cement of constant composition cannot be made in this district. But hydraulic cement has been produced which has given good tests, nearly as good as Portland requirements.

There undoubtedly is however a market for a good natural cement at a reasonable price which can be used instead of Portland for much minor construction. There is also a field for the manufacture of plasters and cement mortars, for which the Niobrara will furnish the raw material. The completion this fall of the line of the Northern Dakota Railway Company from Edinburg to Concrete will undoubtedly lend considerable stimulus to the industry.

The Pembina Portland Cement Company has recently been re-organized as the Northern Cement and Plaster Company. The products manufactured by the plant at Concrete have been increased to include Northern bricklayers' cement, hydraulic cement, Northern cement plaster, Northern fiber and Northern stucco. With the improvements recently made the plant has a capacity of 500 barrels per day.

It is a notable fact that the company does not add gypsum to the finished product, and tests made lead us to believe that this would materially benefit the product.

The following analyses of the cement rock are given in addition to those presented on the previous pages:

	Sample No. 2 Per Cent.	Sample No. 3 Per Cent.	Sample No. 4 Per Cent.	Sample No. 5 Per Cent.
Silicia	29.44	19.06	28.84	41.82
Alumina	11.60	7.32	10.94	13.97
Iron	3.38	2.68	4.94	4.23
Lime	20.23	36.92	22.33	12.27
Magnesia	2.17	0.67	0.69	1.43

2. Lower Niobrara, junction of Pembina and Little Pembina rivers.

3. Eight foot layer in cliff northwest of junction Pembina and Little North rivers.

4. Top of Niobrara, Little Pembina north of Olga.

5. Lower Niobrara, Little Pembina two miles south of Pembina river.

The Niobrara shale is very low in magnesia as a rule. At the bluff from which No. 2 was obtained, the Mayo Brick and Tile Company had done considerable sampling and it is reported that the content in lime carbonate at the top is very high.

The manufacture of hydraulic cement and the laboratory tests in cement making with North Dakota materials are discussed at the end of this chapter.

SHALES AND CLAYS.

The following is taken from the Fourth Biennial Report of the Survey, which is devoted entirely to a discussion of the clays of North Dakota. A description of the geological and geographical occurrence of the clays has already been given, so that the following pages will be devoted chiefly to a detailed description of the deposits, to the results of the physical and chemical tests, and to suggestions as to the uses to which the various clays may be put.

Benton. The Benton shales, while probably underlying much of the central part of the state, outcrop only in the Pembina Mountain region, although they have been reported by Upham in the valley of the Sheyenne, near Lisbon. In the Pembina region they are exposed in the deep valleys of the Tongue, Little Pembina and Pembina rivers. About 150 feet of a green and blue clay shale exposed on the Pembina is classified as Benton.

One of the best outcrops is at Mayo, five and one-half miles west of Walhalla, in the deep valley of the Pembina river. The shales are here used by the Mayo Brick and Tile Company, and were studied in detail. The outcrop is on section 33, T. 163, R. 57, and is opposite the junction of the Little Pembina with the Pembina.

About 150 feet of blue and black shales are shown here, the lower sixty feet of which are not well exposed, being covered by a slide from above. The main deposit is quite uniform. It consists of a very fissile clay shale, soft, easily mined and prepared, and slaking readily. It is of a gray color when dried, is almost black when freshly exposed, and contains many dark carbonaceous particles. Small ferruginous concretions are also abundant. Pyrite is found in small quantities, being reduced by the abundant carbonaceous material. In the lower part of the beds some of the carbonaceous matter has been distilled, and the clay has a strong odor of petroleum. The clay is fine-grained, with very little grit, but the concretions are more sandy. It would be almost impossible to eliminate these small concretions in crushing, but they may be easily crushed and mixed with the clay.

The unweathered shale, when crushed finely, requires a great deal of water, as much as 46.3 per cent, being necessary to bring it up to its maximum plasticity, which is only moderate. The clay is somewhat sticky. It can, however, be greatly improved by weathering. A tensile strength of 108 pounds per square inch was obtained from the dry unburned clay.

The burning tests were as follows:

	Cone No. 010	Cone No. 05	Cone No. 03	Cone No. 01	Cone No. 5
Fire shrinkage-Per ct.	2.3	4.3	5.5	7.3	9.3
Absorption—Per cent	...	21.8	18.9	15.8	8.5
Color.....	Orange Red	Orange Red	Red	Red Brown	Dark Brown

The bricklets became steel hard when burned to cone 01, and were strong. Incipient fusion occurred at cone 5, and vitrification at cone 8, but the clay did not become viscous below cone 14.

A chemical analysis shows the clay (No. 5901) to have the following composition:

	Per cent.
Silica	69.90
Ferrie oxide	2.32
Alumina	10.66
Lime	1.04
Magnesia	2.10
Volatile matter	6.09

A weathered sample (No. 5905) of the slide deposit covering more or less the main deposit was also tested. This weathered shale is coated and seamed more or less by yellowish and white colored material. It consists of gypsum, part of which has been reduced by the carbonaceous material to sulphur, and gives considerable trouble in burning. The material of this was evidently deposited near the top of the Benton, which is higher in lime and sulphur (containing thin layers of gypsum crystals) than the lower part, and is consequently a much less desirable clay.

It is a fine-grained clay with little grit, and free from concretions, although containing gypsum crystals. It is a dark olive gray in color. It slaked very easily, and with 30.4 per cent of tempering water became very plastic but rather sticky. It had a high air shrinkage of 8.0 per cent, but dried without cracking, possibly due to the large tensile strength of 192 pounds.

Great trouble was experienced in burning; the clay fused incipiently at low temperatures, before all the sulphur was driven off. The remaining sulphur reduced the iron so that all the bricks had a black color, as have the stiff mud bricks made from it on a large scale. As the clay approaches vitrification the imprisoned sulphur dioxide bloats the clay and makes it valueless. Probably by very careful burning, keeping the clay at low heat for a long time, so as to eliminate all the sulphur, it could be burned successfully. As it is, pressed brick, hollow brick, and drain tile only can be properly manufactured, the thickness through which the sulphur gases penetrate being small. The results of the laboratory burning tests were:

	Cone No. 010	Cone No. 05	Cone No. 03	Cone No. 01
Fire shrinkage-Per ct.	1.7	5.5	6.4	failed by warping
Color.....	l't orange	light red	light red	red brown
Absorption--Per cent.	13.4	6.4	5.8	2.4

The clay becomes incipiently fused at cone 06, was vitrified at cone 4, and became viscous at cone 11. No chemical analysis was made of the sample, but it is evidently lower in iron and higher in lime than the other unweathered shale, due to the fact that it is from a higher horizon. The great difference in plasticity between the two samples is interesting, and shows the great influence of weathering.



Plant of the Northern Cement and Plaster Company, at Concrete

C. P. Berkey,¹ who has examined this property in the interests of its owner, H. A. Mayo, has published two of the following analyses, and one, made by him, was furnished by Mr. Mayo:

	Sample No. 1 Per cent	Sample No. 2 Per cent	Sample No. 3 Per cent
Silicia	61.03	61.52	67.55
Alumina	22.07	18.65	12.40
Ferric oxide	6.53	4.90	5.86
Lime	0.97	0.75	1.74
Magnesia	0.51	1.32	trace
Water	7.92	8.80	10.45

Sample No. 1 was from near the level of the plant, about seventy-five feet above the river, while No. 3 was near the top of the Benton, and sample No. 2 half way between. It is interesting to note the decrease in alumina and the increase in lime upwards.

The clay near the base of the Benton is preferable. It is suitable for the manufacture of red front pressed brick, and if ground very fine or weathered so as to make it sufficiently plastic it may be worked by the stiff mud machine for making bricks, certain grades of hollow ware and tile.

At present the deposit is not on the railroad, the nearest point being the Walhalla branch, about five miles east. A track could be laid down the valley of the Pembina to meet this branch, a distance of six or seven miles. The building of this track is contemplated, and when constructed should open up a good market for the plant already established.

Niobrara. The Niobrara formation which overlies the Benton and is not sharply differentiated from it, outcrops most extensively in the Pembina Mountain region, and forms a considerable part of the strata exposed by the Tongue, Little Pembina and Pembina rivers. It does not, however, contain any shale valuable as a clay. This is due to the high lime content, varying from twenty to seventy-five per cent of calcium carbonate. This makes certain beds of it valuable for the manufacture of natural cement, but destroys all its usefulness as clay.

The main part of the formation classified as Niobrara, known as "cement rock," is rather hard and massive, breaking out in large

¹American Geologist, March, 1905, p. 151

pieces. It is of a gray color, and contains white specks of carbonate of lime. The uppermost part of the Niobrara is chalky in appearance, often carrying gypsum, iron concretions and thin layers impregnated with alum. The cement shales which are high in lime, burn white at low temperatures, and those which are much lower in lime cream colored, but none of these are of use in the manufacture of clay products.

Pierre. The Pierre forms the uppermost horizon of the Cretaceous shales, and underlies the entire east central part of the state, forming a belt probably a hundred miles wide north and south. It is for the most part covered with a thick deposit of glacial drift, so that it is only exposed where the larger streams have cut down into it. The best outcrops occur along the Pembina, Little Pembina and Tongue rivers, where these have worked back into the escarpment bordering the Red River Valley. Outcrops are also found on the Park, Forest and Turtle rivers. The Sheyenne and James rivers have also eroded through or into the Pierre shales. Along the Sheyenne they outcrop at many points from its source to points below Valley City. Good exposures occur along the James river and Pipestem creek near Jamestown and a few miles north. The Pierre thus not only underlies the central part of the state, but is exposed in many places, and is thus available for use.

In general the Pierre is quite uniform throughout its whole extent. It consists of a dark gray, blue, or black carbonaceous shale. It is fissile and weathers easily into thin plates. The shale is fine grained but contains a little very fine sand. It also contains many small iron concretions which weather out and are seen scattered around the base of an outcrop. This iron stains the clay brownish when weathered. Though high in iron, no samples of the Pierre are high enough in lime to give any effervescence with acid. Just what percentage of lime is present it is impossible to say, as all the samples were collected too late for a chemical analysis, but it is undoubtedly low.

About 300 feet of Pierre shales are exposed in the Pembina Mountain region. The lower part consists of a very fissile, dark gray to black carbonaceous shale. It weathers out into very thin small flakes. Scattered along the outcrop are seen many small iron nodules.

An examination of the shale exposed along the main Pembina river for two or three miles north of Mayo was made and a sample,

(No. 5906), was collected about two miles north of the Mayo brick plant, and fifty feet above the base of the Pierre. The shale here is very fine grained, with but little grit. It contains however, a few small pyrite concretions, which weather to limonite. The clay is not very hard and could be easily mined and crushed. It does not slake so readily as the Benton, a piece one inch in diameter took two days to slake completely when immersed in water. It required 34.0 per cent of water to temper it to its maximum plasticity, which was good but very sticky. The air shrinkage was 8.7 per cent, and the tensile strength 94 pounds. In spite of its high shrinkage it did not crack in drying, except for a few small cracks on the surface.

The burning tests were as follows:

	Cone No. 010	Cone No. 05	Cone No. 03	Cone No. 01
Fire Shrinkage—per ct.	1.5	5.9	5.0	failed by warping
Color	pink	light red	light red	red brown
Absorption—per cent	17.5	9.4	9.7	4.0

The sulphur present in the pyrite caused all the brick to have a black core, and was also the reason of the failure of the bricklet burned to cone 01. Because the cones tested for fusibility were so small that the sulphur was completely eliminated, and the iron oxidized to a ferric condition, incipient fusion took place at cone 05, but vitrification not until cone 7, and viscosity at cone 14.

No chemical analysis was made of this sample. Although this particular sample was so high in sulphur as to be practically worthless for any ware manufactured by the stiff-mud process, good red dry-press brick could be made. Then, too, the sample which was taken directly from the outcrop does not represent the best grade of shales in the neighborhood.

A deposit of clay near Olga is described by E. J. Babcock as a fine white clay of a slightly acid taste two to three feet in thickness. This is probably in the Pierre horizon, but higher than the beds exposed along the Pembina, being overlain and underlain by black carbonaceous clay shale. It stands a high temperature and burns to a slightly pinkish tint. An analysis shows the following composition:

	Per cent.
Silicia	50.45
Alumina	17.57
Ferric oxide	2.80
Lime	0.25
Magnesia	1.79
Potash	0.07
Soda	0.86
Water and volatile matter	22.55
Other matter	3.66

The clay could be used for stoneware and as a low refractory clay.

Pleistocene. The valleys of the northward flowing rivers were damned up by the edge of the retreating ice-sheet toward the close of the Glacial Period, and great lakes were formed. Lake Agassiz occupying the Red River Valley was one of these. Clay was introduced by the inflowing streams and deposited on the bottom. The sediments thus laid down are sandy and calcareous and were derived mainly from the Pierre and other Cretaceous shales, and from the glacial drift. These stratified clays reach a thickness of from fifty to 100 feet in the Red River Valley.

Only the yellow subsoil underlying the surface loam has been employed as yet for the manufacture of brick. This consists of a sandy, calcareous clay which is very uniform in its character and properties throughout the valley. It is overlain by a foot or two of black surface loam, from eight to ten inches of which are stripped off in working. Directly underlying the yellow clay is a mottled yellow and blue clay about three feet thick, known as "joint clay." It is harder than the overlying material and grades downward into a blue clay of indefinite thickness. The typical yellow clay which is dug for brick is about three and one-half feet thick at Drayton and thins out towards the south, so that the pits at Fargo and Abercrombie are very shallow, only two feet to eighteen inches being used. At Grand Forks about a foot of the joint clay is mixed in with the yellow. The clay is rather sandy, is light and porous, containing roots and other carbonaceous material. It is colored yellow by the oxidized iron, is highly calcareous and carries small lime pebbles and mica. It only develops a moderate plasticity, and fuses at a low temperature (about 2,200 degrees F.), with a very small range of from 100 to 200 degrees F. between incipient fusion and viscosity. The bricks when underburned are pink, but properly burned at 2,000 degrees F. are cream colored.

At Drayton there is exposed¹ in the pits about three and a half feet of yellow clay, overlain by eight or ten inches of black loam, and underlain by the joint clay grading into the blue clay. The yellow clay is sandy and is high in carbon, iron and lime. It is soft enough to go directly from the pit to the pug mill. It required 26.3 per cent of tempering water and developed a moderate plasticity. It had an air shrinkage of 4.8 per cent and the tensile strength of the air dried clay was 173 pounds. The burning tests were as follows:

	Cone No. 010	Cone No. 05	Cone No. 03	Cone No. 01
Fire shrinkage—Per ct.	1.0	1.4	1.0	1.9
Color	l't cream	l't cream	cream	light greenish
Absorption—Per cent	29.7	30.5	30.7	24.2

The bricklets were strong and those burned to 01 nearly steel hard. Incipient fusion occurred at cone 2, vitrification at cone 4, and viscosity at cone 5.

BOULDERS, GRAVEL AND SAND.

Boulders, gravel and sand occur in some abundance throughout the area. They are quite plentiful in the Pembina Mountains and west of the escarpment.

The boulders include Archean granites, gneisses and schists, crystalline and igneous, and Cambro-Silurian limestone. They are of great importance locally as a building material, especially for foundations. They are also an admirable material for road foundations.

Boulders are very abundant in "The Mountains," a morainic ridge in Golden and Lampton townships, and lying east of the Golden Valley. They are found in greatest number on the west side of this deposit. West of Edinburg along the railway, there is a large quantity of boulders lying scattered on the surface to the south, and on the north end of the Golden Valley. Boulders are very plentiful along the escarpment of the Pembina Mountains, and in the valleys of the streams. They have been concentrated there by the erosion of the overlying drift. Boulders are especially plentiful in Cavalier county in the portions indicated as morainic on the map.

Gravel is a good road material, and also very useful in making concrete. There are a few pockets of it in "The Mountains," especially on the east side, but there is also a great deal of clay with this deposit. Gravel is found in the Herman and Norcross beaches especially in the vicinity of Edinburg. In section 36, Fremont township, section 31, Walhalla township, and sections 6, 7, and 18, Liberty township, there is considerable gravel. This was deposited along an old outlet of the Pembina river. There is a little gravel in the valleys of the Pembina Mountains but there is usually too much associated shale to make it of value. There is some gravel in the morainic areas of Cavalier county, but there is usually too much associated clay.

Sand is of great value as a building material and for working in clay roads. There is a considerable amount of good sand on the eastern slope of "The Mountains." It is also found in the Herman, Norcross, Tintah, Campbell, McCauleyville, Hillsboro, and Emerado beaches. The Campbell Embankment contains much good sand for road construction. The Campbell beaches northwest of Walhalla contain very good sand. The sand of the Pembina delta is very fine and silty to the east, but is very good in the western part.

WATER SUPPLY.

Water for domestic use and for stock is of great economic importance in this region. During seasons of drought in the early nineties there was considerable agitation in favor of irrigation by well waters. Such a course will probably never be adopted for in average seasons the soil is quite moist. Further, the yield of the wells is so small as to make such a method of farming too expensive for the common crops, and after a number of years the soil would be rendered useless by the deposition of much saline matter from the waters.

The problem of obtaining suitable water for drinking purposes is a serious one, especially in the neighborhood of Cashel, and north and east of there along the line of the Northern Pacific to Carlisle. In this district water is not only scarce but that which is obtainable is usually quite salty and bitter. In the immediate vicinity of Cashel water is often hauled from wells four or five miles distant in order to supply the ordinary demands of the farm.

This discussion of the water supply is necessarily of a preliminary nature on account of the large amount of time which would have been required for a detailed investigation. However, data is constantly being gathered in addition to that which has already been published.¹

In general the river waters of this region are good when filtered to remove their suspended material, but with the growth of cities and towns along their banks and the increase of stream pollution by waste matter and sewage, the danger of bacterial infection becomes correspondingly great. At best these waters are available to those favored few who are located near a supply of this sort.

The main dependence of the region then is upon well waters. These may be provisionally divided into three classes: deep artesian wells (the source of water is unmistakably beneath the drift); artesian wells in the drift; and common wells.

The deep artesian wells are found in greatest numbers in the Red River Valley region. Unfortunately, the only available sources of information in regard to these wells are some of the published reports just mentioned. The description of the wells differ in many important generalizations as well as in most of the details and on this account no positively accurate statement in regard to the source of water supply can be made. Upham states that the water of the Grafton well comes from the St. Peter sandstone. In nearly all cases the waters of these deep artesian wells are briny and bitter, although they can be used in municipalities for fire protection and street watering, and on the farm for stock. West of the Pembina escarpment there are few deep wells.

The following sections are from some of the best known deep artesian wells.

Hamilton well.—Located in section 35, T. 162, R. 53, town of Hamilton, county of Pembina. Owned by the Hamilton Artesian Well Company. Commenced November, 1887. Completed, August, 1889. Drilled by W. B. Clements, Cavalier, North Dakota. Depth,

¹51st Congress, 1st Session, Senate Ex. Doc. 222; A Report on the Preliminary Investigation to Determine the Proper Location of Artesian Wells Within the Area of the 87th Meridian and East of the Foothills of the Rocky Mountains, 1890.

52nd Congress, First Session, Senate Ex. Doc. 41; A Report on Irrigation and the Cultivation of the Soil Thereby 1892.

17th Ann. Report, U. S. G. S., part 2, 1895-96.

Mon. XXV, U. S. G. S., Glacial Lake Agassiz, Warren Upham, 1896.

Water Supply Paper, No. 61, U. S. G. S., Preliminary List of Deep Borings in the United States, Part II (Nebraska-Wyoming), N. H. Darton, 1902.

Folio 117, Geologic Atlas, U. S. G. S., Fargo and Casselton (N. D.), Quadrangles, Bull. 319, U. S. G. S., Summary of the Controlling Factors of Artesian Flows, M. L. Fuller, 1908.

1,560 feet. Cost, \$10,150 or \$6.50 per foot. Flow, 26 gallons per minute. Pressure, 27 pounds per square inch when flow is shut off. Temperature of water, 41½ degrees. Elevation above sea level, 824 feet.

Strata	Thickness Feet	Total Feet
Soil	10	10
Blue clay	122	132
Coarse sand (surface water)	42	174
Hard pan (cemented gravel)	15	189
Quicksand	4	193
Red shale	32	225
Blue shale	20	245
Red shale	43	288
Gray limestone	12	300
Blue shale (flow)	7	307
Gray limestone	277	584
Pink limestone	25	609
Gray limestone (very soft)	153	762
Blue shale (caving)	130	892
White sandstone	5	897
Blue granite	344	1241
White sand (main flow)	1½	1242½
Blue granite	1½	1244
White sandstone	315	1560

This bore was put down for a test well, and with the hope of obtaining a supply of water for city purposes. Two small flows of salt water were struck, one at three hundred feet which flowed 80 gallons per minute, the other at 1241 feet, which at first flowed 45 gallons of brine per minute. The water contains 2000 grains of salt per gallon. The bore is cased with 6-inch casing to 350 feet. Inside of this is a string of 897 feet of 4-inch, which starts from the top. There are 600 feet of drill poles, and a drill in the bottom of this bore. The lower 350 feet are in what is supposed to be Laurentian granite. The bottom of this bore is 736 feet below sea level.

Grafton well.—Located in section 13, T. 157, R. 53, town of Grafton, county of Walsh, N. D. Owned by town of Grafton. Commenced February 24, 1885. Completed June 20, 1885. Drilled by Swan Bros., Andover, South Dakota. Depth 912 feet, cost \$3,800, or \$4.16 per foot; flow, 600 gallons per minute; pressure, 12 pounds per square inch when flow is shut off; temperature of water, 46 degrees; elevation above sea level, 825 feet.

Strata	Thickness Feet	Total Feet
Soil	3	3
Yellow clay	10	13
Blue clay	90	103
Gravelly clay (blue)	30	133
Quicksand (clayey)	22	155
Hard pan	40	195
Sand and gravel (white light flow)	30	225
Sand (coarse white)	20	245
Red shale rock	10	255
Lime rock (reddish)	2	257
Red shale	13	270
White sand rock (flow of water)	60	330
Blue shale	3	333
Red shale	3	336
Lime rock (gray)	4	340
Red shale and lime streaks	48	388
Green shale (brine flow)	2	390
Gray lime rock (gritty)	5	395
Magnesian lime rock	200	595
Cream-colored lime rock	105	700
Red shale and lime rock	45	745
Blue shale	135	880
Red shale (gritty)	20	900
Sand and quartz (white)	3	903
Granite (gray)	9	912

This well was put down for municipal purposes. The water being salty, is not suitable for domestic use, although used for watering stock, for fire purposes, and for sprinkling streets. No flows were found below 390 feet, and the bore was purposely filled up to this point. When allowed to flow freely considerable sand is thrown up. The water contains 240 grains of salt per gallon, with a small amount of Epsom salt. The well is cased with 160 feet of 8-inch casing, and 290 feet of 6-inch. The latter starts from the top and is seated in the sand rock 100 feet above the lower flow. The lower end of the bore penetrates 9 feet into gray granite. Just above this is a 3-foot stratum of sand and quartz rock.

A record of the well at the Honey mill at Park River was contributed by Messrs. Honey, Dunn and Metz. In general it is as follows: Soil and till are met with down to 16 feet where there is a layer of boulders; a dark blue gumbo clay continues to almost 100 feet; there follows 5 to 7 feet of water bearing dark sand, furnishing water to within 25 feet of the top; blue clay with little variation continues to nearly 300 feet; here occurs a sand layer 7

to 8 feet thick, which furnishes water to within 85 to 90 feet of the top, the present supply. The well then continues through hard conglomerate, and it was impossible to obtain the rest of the record.

Throughout the Red River Valley region there are a large number of artesian wells in the underlying glacial drift. Their depth is usually from 100 to 350 feet. After penetrating the overlying deposit of soil and lacustrine clay these wells cut through many varieties of glacial drift or till. Much of this glacial material consists of clay with included rock fragments. However, there are in these clays many gravel and sand layers and these act as reservoirs for the water. They are very irregular in shape and occurrence, as is shown by the great variation in well logs in the same locality. These waters are usually hard, and often alkaline and bitter, especially in the vicinity of Cashel and north of there. Some have attempted to account for the water in these gravels and sands by supposing that the water was supplied by rain falling and soaking into the coarse gravel and sand beaches in the western part of the valley. But these gravel and sand layers are as irregular in an east-west direction as in a north-south one, so that it is hardly possible that the water is supplied directly in that manner. Furthermore, it should be emphasized that there is no reason for thinking that the beach deposits are continuous from one ridge to another. Probably the gravel and sand are the result of a halt in the recession of the lake so that they were concentrated along those lines, being derived from the drift materials of the vicinity. Others have claimed that much of this water was supplied from the Pembina Mountain region by water running down on the surface of the shale. But these shales do not continue very far to the east, and this would leave the supply far to the west of the wells and opposed by a clay barrier. As previously mentioned, it is probable that the Dakota sandstone was encountered in the Park River well at 300 feet. Upham has shown that the Dakota sandstone rises to the east and perhaps forms the bed-rock of the middle and western part of the Red River Valley, though it is probably thin.

The Dakota sandstone which underlies North and South Dakota and Nebraska rises to the west and comes to the surface in the Black Hills and in the foothills of the Rocky Mountains. Here it collects its supply of waters, which is able to circulate through it because of the porous character, and also on account of lying between relatively impervious beds. During its journey the water takes

a quantity of salts into solution. Upham¹ has shown that with the removal of the overlying shales, the water of the Dakota would make its way upward upon arriving east of the Pembina escarpment. This is undoubtedly what actually takes place, as is shown by many facts. The waters are more alkaline and salty than would be expected if their minerals were derived from the drift. It is difficult to account for the necessary head of many of the wells in any other way. There are salt springs rising through the drift in many places, especially near Cashel, on the Park river, and on the Forest river.

Common wells are very numerous in western Pembina county and in Cavalier county. As a rule they vary from ten to fifty feet in depth. In the Red River Valley region their waters are usually hard, but are without alkali, while west of the escarpment they are often alkaline. East of the line of the sandy beach lines of the Red River Valley common wells are relatively scarce. There are many fine wells in this region which are dug in the old beaches or deltas. Water is found near the bottom of the deposits, due to seepage, and is usually of good quality. Most of the common wells cut through the overlying soil and lacustrine material and into the drift deposit until they encounter a favorable water bearing gravel or sand. Conditions vary quite widely throughout the region.

¹Mon. XXV, U. S. Geol. Survey, p. 535.

THE MANUFACTURE OF NATURAL HYDRAULIC CEMENT.

BY V. J. MELSTED.

Inasmuch as the manufacture of hydraulic cement may be an important industry in North Dakota, a brief account concerning its manufacture is given here. As there are many books treating of the subject in a very thorough manner, this article will be limited to the methods peculiar to and adaptable to conditions surrounding the manufacture of cement in this state.

There are three kinds of cement materials: 1st, those that owe their hardening qualities to the action of air; 2d, those that owe their hardening qualities to the action of water, and 3d, those that owe their hardening in some degree to both air and water. To the first class belong common lime, which simply absorbs the carbon dioxide from the air and resumes its original composition of calcium carbonate. To the second class may be referred two distinctly different types of cements. (a) Those that by taking up water resume their original composition, such as gypsum plasters. (b) Those that undergo a distinct chemical change with the formation of compounds entirely different from those constituting the raw material, such as hydraulic and Portland cements. To the third class belong the hydraulic limes which partake of the characteristics of both hydraulic cements and of lime. They are essentially a mixture of hydraulic cement and free oxide of lime.

THE NATURE OF CEMENT.

A cement may be said to correspond approximately in composition to a pure tri-calcic silicate ($3 \text{ Ca O}, \text{Si O}_2$) or to a compound containing very nearly three parts of lime to one part of pure quartz sand. In practice, however, such a cement is never made, since more or less of other ingredients always enter into the mixture. The silica is replaced by alumina and iron oxide and in hydraulic cements magnesium oxide may replace the lime.

The distinction between Portland cements and hydraulic cements lies in the fact that in Portland cement the lime, silica, iron and alumina are always mixed in a certain ratio which has by experi-

ence been found to result in the formation of certain definite chemical compounds, and a slight change in this ratio will prohibit the formation of these compounds, or in addition to them others which are prejudicial to the soundness of the cement also form. With natural or hydraulic cements, however it is different. Widely varying mixtures are used, usually only those already mixed in nature, and these naturally vary much in different localities. A Portland cement is usually made unsafe only by an excess of the lime constituent; too low lime simply brings it into the class of natural cements.

North Dakota is fortunate in possessing an extensive supply of raw material suitable for the manufacture of natural cement. This material has been referred to in the foregoing report as "cement rock." And a cement rock it truly is, since much of it so closely resembles an ideal Portland cement mixture in composition that a slight increase in the lime content would bring it up to first class Portland cement material. But it has so nearly this composition as it is found that a very high grade natural cement is made from it with no artificial mixing whatever. The great advantage of this may be fully realized when it is conservatively stated that to make artificial Portland costs at least three times as much as to make the natural cement, conditions of labor, fuel and transportation being the same.

MANUFACTURE OF NATURAL CEMENTS.

In the manufacture of a cement there are three well defined stages in the process: 1, winning of the material; 2, burning; and 3, grinding.

Considering only the North Dakota deposits of cement rock, there are two available ways of getting the material, by mining and by stripping the overburden and excavating the rock with a steam shovel. By far the greater amount of rock can be obtained only by mining, as it is deeply buried under the overlying Pierre. Mining is expensive in comparison with stripping, but it has certain obvious advantages which cannot be overlooked. By mining, the rock is generally secured dry, whereas, in an open pit wet weather makes it very disagreeable to handle. Furthermore, a mine can be operated in winter as well as in summer, while an open cut method in our climate could be employed only in summer, and would necessitate large storage sheds if continuous operations were to be carried on. There are several places along the edges of the Pembina Mountains

where stripping could be carried on and many places along the ravines where tunnels could be run in. Which method shall be pursued will depend upon circumstances surrounding each individual case.

The best method of mining is that used in mining coal, and known as the pillar and room system. A tunnel is first run in and rooms are worked off on both sides, leaving pillars large enough to support the weight of the roof. The main tunnel should be timbered with sets not more than four feet apart, two posts and a cap constituting a set. In the side entries less timbering is required. Ten feet between sets is safe if the roof is occasionally inspected for loose rocks, which should be timbered up to prevent caving. As a rule no lagging is required as the rock is hard, breaks clean, and does not crumble down much under action of the mine air.

Under normal conditions one pound of forty-five per cent dynamite should break loose sufficient rock to produce twenty barrels of finished cement. Of course, with inexperienced miners much more than this may be used, but it is not necessary. Timbers should be cut to measure and fitted outside the mine entry, as this is apt to be done in a slipshod manner inside the mine. The mine should be well drained by ditches leading to a sump in which the water should be kept well below the surface of the mine floor.

Burning. The burning constitutes probably the most important part in the whole process of cement manufacture. With a poor burn there will result poor cement, no matter how good the raw material may be. There are two types of kilns in use for burning natural cement, an intermittent kiln, and a continuous kiln. The intermittent kiln is practically going out of use. It resembles an ordinary lime kiln. The rock is piled on top of the grates and then the fire is built under it and kept burning until the whole mass above is sufficiently burned. Such a kiln is slow in operation and requires much fuel.

The continuous type now most commonly in use is a straight shaft kiln about ten feet in diameter and forty feet high. At the top it narrows down to seven or eight feet in diameter, this shape causing it to have a better draft. The lower part is lined with ordinary or low grade fire brick, while the top is lined with high grade fire brick. To start operations the kiln is filled with raw rock to within four or five feet of the top, and a fire is then started on top of this rock. When a good bed of fire has been secured

more rock is dumped in and more coal on top of that, and thus in alternative layers the rock and coal is continuously thrown in. The raw rock is drawn out from the openings at the bottom just as fast as the burner judges the rock is getting burned on top. After the kiln has been in operation some time burned rock begins to appear. This is termed clinker and goes to the mill to be ground to cement.

The clinker should be burned so that it is dark gray, with a stony appearance. It feels heavy and is rather hard to break. If it is underburned it is yellow and crumbles down to dust very easily, while if overburned it has the appearance of glass, is very hard and difficult to break. To burn properly is an art which is acquired not by any amount of theory, but by a great deal of practice and close observation.

Grinding. After the raw rock is burned it comes out of the kiln in various sized lumps. While in this condition it is little affected by water and possesses little if any cementing power. The reason for this is not quite plain, but it is known that the chemical activity of many substances increases with an increase in the fineness of the material, and in the case of cements experiments have shown that it is only the finer portion of the ground cement that has any cementing power. The residue caught on a sieve having 10,000 meshes to the square inch is no better than so much sand; while that which remains on a sieve with 40,000 meshes to the square inch is only feebly cementing. For this reason it is apparent that the fine grinding of cement is very important. Formerly natural cements did not receive the same attention as to fine grinding that Portland cements did, but there is no valid reason why at least the better grades should not receive the same care. With the poorer grades fineness does not alter their value to such a marked degree but the tendency is to grind all grades finer.

Various types of grinding machinery are in successful use. The one most commonly employed consists of some form of jaw or rotary crusher for preliminary grinding, a ball mill for intermediate grinding, and a tube mill for finishing the product.

A jaw crusher, as the name signifies, does its crushing by means of a pair of powerful jaws which are made to alternately open and shut, crushing the material between the jaws when they close together. A rotary crusher acts on the same principle as a coffee mill, only on a large scale, and they vary in size from a little laboratory crusher to immense machines capable of crushing rocks

weighing a ton or more. For rock or any material that is not very hard they are far more economical in operation than the jaw crusher and for most natural cement clinker they form an ideal preliminary crusher.

A ball mill is a hollow cylinder revolving on an axis at the rate of twenty to twenty-five revolutions a minute. The mills vary in size but are commonly six to eight feet in diameter and three to four feet long. They are lined with heavy steel plates and half filled with steel balls varying from three to five inches in diameter. The revolving of the mill causes the balls to roll over each other and tumble about, in so doing reducing the material to be ground. They require from forty to fifty horse-power each.

A tube mill is similar in principle to a ball mill but only five to seven feet in diameter and from sixteen to twenty-two feet long. It may be lined with wood, cast iron, steel or a porcelain-like material termed silex. Instead of steel balls they are half filled with flint pebbles. The material is fed in through a tube at the center of one end of the mill and passes the entire length, being discharged at the periphery of the other end, which is covered with a screen to prevent the discharge of pebbles. A tube mill makes from twenty-five to thirty revolutions a minute, according to size and requires from 75 to 100 horse-power.

A mill equipped with one rotary crusher, one ball mill and two tube mills, working on good natural cement clinker has an approximate capacity of 800 to 1,000 barrels every twenty-four hours with an expenditure of about 225 horse-power for grinding. Of course some extra power would be required for conveyors, depending upon the interior arrangement of the mill.

The above grinding machinery is expensive to install and consumes much power but costs comparatively little for repairs and insures steady running, as it is very seldom that a breakdown occurs with these machines.

However, for all clinkers except the very hardest an emery mill may economically replace both ball and tube mills, taking the crushed product from the rotary crusher and finishing it in one operation. An emery mill consists of two flat disks running against each other or one may be stationary while the other one revolves. The disks are made with pieces of emery radiating from the center, usually set in an iron frame. This emery is exceedingly hard and resists wear to a remarkable degree, yet these disks require periodical dress-

ing to keep the grinding surface even. When the disks are worn out they may be replaced at a nominal cost. To equal in capacity the ball mill and two tube mills would require five or six emery mills, which would cost but little more than one tube mill and save at least seventy-five horse-power over what the tube and ball mills require.

After grinding, the cement is sacked in stout canvas bags, eighty-eight pounds to a bag, and three bags constitute a barrel. A better method would be to run it into bins and store it in these for two or three weeks before sacking. This gives it a chance to "cure" and insures a more uniform and better product.

LABORATORY TESTS IN CEMENT MAKING WITH NORTH DAKOTA MATERIALS.

BY V. J. MELSTED.

These tests show what can be done in the way of producing cement from the cement rock in the state.

The laboratory work consisted of the analysis of several samples of cement rock and of chalk suitable for mixing with the cement rock to make a proper proportion of cement. The natural cement rock was given several different burns and the resulting clinker ground, mixed with various proportions of gypsum and subjected to all the usual tests of cement. The cement rock was further mixed with chalk in correct proportions as determined by the analysis, given different burns, ground up and varying proportions of gypsum added, and these were then subjected to the usual Portland cement tests.¹

RECORD OF TESTS.

The rock used for burning the natural cement had the following composition:

	Per cent.
Silica	14.37
Calcium carbonate	61.50
Alumina	6.87
Ferric iron	2.36
Magnesia	Trace
Sulphur trioxide	0.75
Bituminous matter	8.00

The bituminous matter was determined in the following way, which though not very accurate give fairly close results. One gram of the finely powdered and thoroughly dried material was dissolved in hydrochloric acid. The residue was filtered, well washed and dried on the hot air bath. It was then weighed and ignited at a low red heat to constant weight. The difference in weight between the dried and ignited residue was determined as bituminous matter. The error most likely to result from this procedure is in the burning off of some of the sulphur which may be present

¹These tests were made as part of the work of a thesis in the North Dakota School of Mines at the State University.

in the form of pyrites. This, however, would be only very small and the method is quick and gives a good idea of the amount of bituminous matter present.

The cement rock was broken up into sizes varying from the size of a hazel nut to that of a chestnut. It was then fed in alternate layers with soft coal into a small circular kiln, in which a good bed of coke fire had been previously prepared. In this way about one-half pound of cement rock could be burned at a single burning, and about half the clinker was underburned. By this method practically all the sulphur was burned into the cement, causing the resulting product to have a spotted appearance when made up into briquettes. To get rid of this sulphur a slightly different method of burning was tried. Instead of preparing a hot bed of fuel before introducing the cement rock the fire was allowed to get only a slight start before putting in a layer of rock. This, however, did not seem to help matters any, and the resulting cement had exactly the same appearance as that which was previously burned. Several more burns were made in this manner but on account of the small amount of rock which could be burned at a time a continued operation of the kiln was tried. This method worked exceedingly well. The hot clinker was drawn through the draft hole at the bottom of the kiln and fresh fuel and rock introduced at the top. In this way over five pounds of rock were burned in one day. The resulting clinker was sorted into three different groups: underburned clinker, normal clinker, and overburned clinker. The underburned clinker had a yellowish, chalky appearance and was very soft and easily ground. The normal clinker was a dark gray, very hard, and had a decided stony appearance, while that which was overburned was nearly black and glassy.

PHYSICAL TESTS OF NATURAL CEMENT.

Normal Cement.

NO GYPSUM.

	Pounds.
7-day neat	225
28-day neat	293
7-day 3:1 sand	136
28-day 3:1 sand	144

For a normal consistency twenty-three per cent of water was required for the neat cement, and nine per cent for the 3:1 sand mortar. The color of the briquettes was very dark on the broken

surface. This was probably due to the presence of too much sulphur. The broken briquettes upon exposure to the air gradually assumed a normal grayish color.

Initial set: five minutes.
 Final set: ten minutes.
 Fineness: 100 per cent through 100 mesh.
 80 per cent through 200 mesh.
 Specific gravity: 3.12.

GYPSUM TWO PER CENT.

	Pounds.
7-day neat	307
28-day neat	412
7-day 3:1 sand	223
28-day 3:1 sand	294

Initial set: ninety minutes.
 Final set: six hours.
 Normal consistency: for neat 23 per cent of water.
 Normal consistency: for 3:1 sand 9 per cent of water.
 Boiling test: O. K.
 28-day pat: O. K.

GYPSUM FOUR PER CENT.

With four per cent of gypsum the cement did not acquire its initial set in twenty-four hours, and after the briquettes had been in the molds for four days they were taken out while they were not yet hard. No further tests were made on this sample as it was evidently worthless.

GYPSUM ONE PER CENT.

	Pounds.
7-day neat	422
28-day neat	530
7-day 3:1 sand	233
28 day 3:1 sand	250

Initial set: forty-five minutes.
 Final set: two hours.
 Normal consistency: 23 per cent of water for neat.
 Normal consistency: 9 per cent for 3:1 sand.

The color of these briquettes was greatly improved over that of the cement without any gypsum. From these tests it would appear that one per cent of gypsum is highly desirable as an addition to this cement. More than one per cent of gypsum does not have as good an effect and as it is desirable to add as little gypsum as possible the lowest percentage accomplishing the desirable results should be used. The cement with one per cent of gypsum comes very near to the standards of Portland cement and could be used for all practical purposes instead of artificial Portland with very satisfactory results. It is entirely safe, but rather low testing Portland.

Underburned Cement.

NO GYPSUM.

	Pounds.
7-day neat	164
28-day neat	183
7-day sand	163
28-day 3:1 sand	174
Initial set: fifteen minutes.	
Final set: twenty minutes.	
Fineness: 100 per cent through 100 mesh.	
93 per cent through 200 mesh.	
Normal consistency: 45 per cent of water for neat.	
17 per cent of water for 3:1 sand.	
Specific gravity: 2.6.	
Normal pat: softened on boiling.	

GYPSUM TWO PER CENT.

	Pounds.
7-day neat	175
28-day neat	191
7-day 3:1 sand	169
28-day 3:1 sand	174
Initial set: fifteen minutes.	
Final set: twenty minutes.	
Normal consistency: 45 per cent of water for neat.	
17 per cent of water for 3:1 sand.	

GYPSUM FOUR PER CENT.

7-day neat	173
28-day neat	165
7-day 3:1 sand	159
Initial set: twenty minutes.	
Final set: thirty minutes.	
Normal consistency: 45 per cent of water for neat.	
17 per cent of water for 3:1 sand.	

GYPSUM SEVEN PER CENT.

	Pounds.
7-day neat	193
28-day neat	180
Initial set: twenty minutes.	
Final set: thirty minutes.	
Normal pat: softened on boiling but was O. K. after 28 days in water.	

As previously stated the clinker from which this cement was made was soft, yellowish in color and very easily ground. When passed once through a disc mill it came out in a very fine floury state. It is in all ways equal to the ordinary natural cements which are on the market. On account of the bituminous matter in the rock it can be made with but very small fuel consumption and on account of the softness of the clinker the expense of grinding would be very low. For sand mortars it would be equal to lime in every way and would have many advantages on account of its hydraulic properties.

From the previously recorded tests it appears that the cement is but slightly effected by the addition of gypsum and in that respect differs most markedly from the well burned normal natural cement made from this rock.

Overburned Cement. This glassy clinker when ground furnished a product which had no more cementing powers than any other finely ground slag or sand. It would appear that any particles of overburned clinker would have no injurious effect if present in the normally burned clinker. It would serve simply as any other inert but harmless adulterant.

PHYSICAL TESTS OF PORTLAND CEMENT.

The following is the analysis of the cement rock used for the first mixture to produce Portland cement:

	Per cent.
Silicia	14.47
Calcium carbonate	68.04
Alumina	6.12
Iron	2.66
Magnesia	none
Sulphur trioxide .....	.73

The following is an analysis of chalk used for mixing with the cement rock to bring up the lime content of the former to a Portland mixture:

	Per cent.
Silicia	1.39
Calcium carbonate	97.94
Alumina and ferric oxide .....	.6
Magnesia .....	.76
Sulphur trioxide	none

For the second mixture of raw materials a cement rock having the following composition was used. The same chalk was used for bringing this up to a Portland mixture as was used for the other mixture:

	Per cent.
Silicia	15.11
Calcium carbonate	61.43
Alumina	6.59
Ferric iron	2.17
Magnesia	trace
Sulphur trioxide .....	.97

The proper proportion of cement rock and chalk for the first mixture was found upon calculation to be ten parts of chalk to one hundred parts of cement rock. This, when mixed and finely ground, would give a cement fairly high in lime, but without danger of being overlimed if properly burned.

The proportion for the second mixture was determined to be fifteen parts of chalk to one hundred parts of cement rock.

The cement rock and chalk were first passed through a jaw crusher and then ground to the proper fineness in a small tube mill. Some trouble was experienced in keeping the mixture from balling up in the tube mill; but by introducing only a small amount of the mixture at a time and keeping a good charge of flint balls in the mill a satisfactory grind was obtainable. The materials after being ground were wetted and made up into round balls the size of a large hazel nut. These were dried preparatory to burning in the small vertical kiln. The continuous method of burning previously referred to in connection with burning of natural cement was used. On account of the high point of fusibility of this clinker none of it came through sufficiently burned the first time, but by passing it through the kiln a second time only a small amount of underburned clinker remained. The underburned clinker was carefully separated and the two kept separate during grinding. A small amount of overburned clinker was secured, but not in sufficient quantities for testing purposes.

UNDERBURNED CEMENT.

	Pounds.
24-hour neat	198
7-day neat	225
7-day 3:1 sand	140
Initial set: ten minutes.	
Final set: twenty-five minutes	
Fineness: 93 per cent through 200 mesh.	
Normal consistency: 35 per cent of water for neat.	
	13 per cent of water for 3:1 sand.
Specific gravity: 2.7.	
Boiling test: pat disintegrated.	

These were all the tests which were made on the underburned portion. They show conclusively the necessity for a thorough burning of the raw materials, even when they do not carry the allowable high limits of lime. These tests along with those made on the underburned natural cement also show the excessive amount of water necessary to bring an underburned free lime cement up to a normal consistency. Also the specific gravity is very much lower than on a normally burned cement.

Normal Portland Cement, first mixture.

NO GYPSUM.

	Pounds.
24-hour neat	311
7-day neat	578
7-day 3:1 sand	253
Initial set: twenty minutes.	
Final set: two hours.	
Fineness: 89 per cent through 200 mesh.	
Specific gravity: 3.12.	
Boiling test: O. K.	
Normal consistency: 24 per cent of water for neat.	
10 per cent of water for 3:1 sand.	
Color: very good.	

GYPSUM ONE PER CENT.

	Pounds.
24-hour neat	293
7-day neat	595
7-day 3:1 sand	275
Initial set: ninety minutes.	
Final set: five hours.	
Boiling test: O. K.	

GYPSUM TWO PER CENT.

	Pounds.
24-hour neat	275
7-day neat	563
7-day 3:1 sand	260
Initial set: two hours.	
Final set: ten hours.	
Boiling test: O. K.	

Normal Portland Cement, second mixture.

NO GYPSUM.

	Pounds.
24-hour neat	325
7-day neat	617
7-day 3:1 sand	240
Initial set: thirty minutes.	
Final set: ninety minutes.	
Normal consistency: 24 per cent of water for neat.	
10 per cent of water for sand mortar.	
Fineness: 87 per cent through 200 mesh.	
Specific gravity: 3.13.	
Boiling test: O. K.	
Color: very good.	

GYPSUM ONE PER CENT.

	Pounds.
24-hour neat	309
7-day neat	618
7-day 3:1 sand	289
Initial set: two hours.	
Final set: six hours.	
Normal consistency: 23 per cent of water for neat.	
9 per cent of water for sand.	
Boiling test: O. K.	

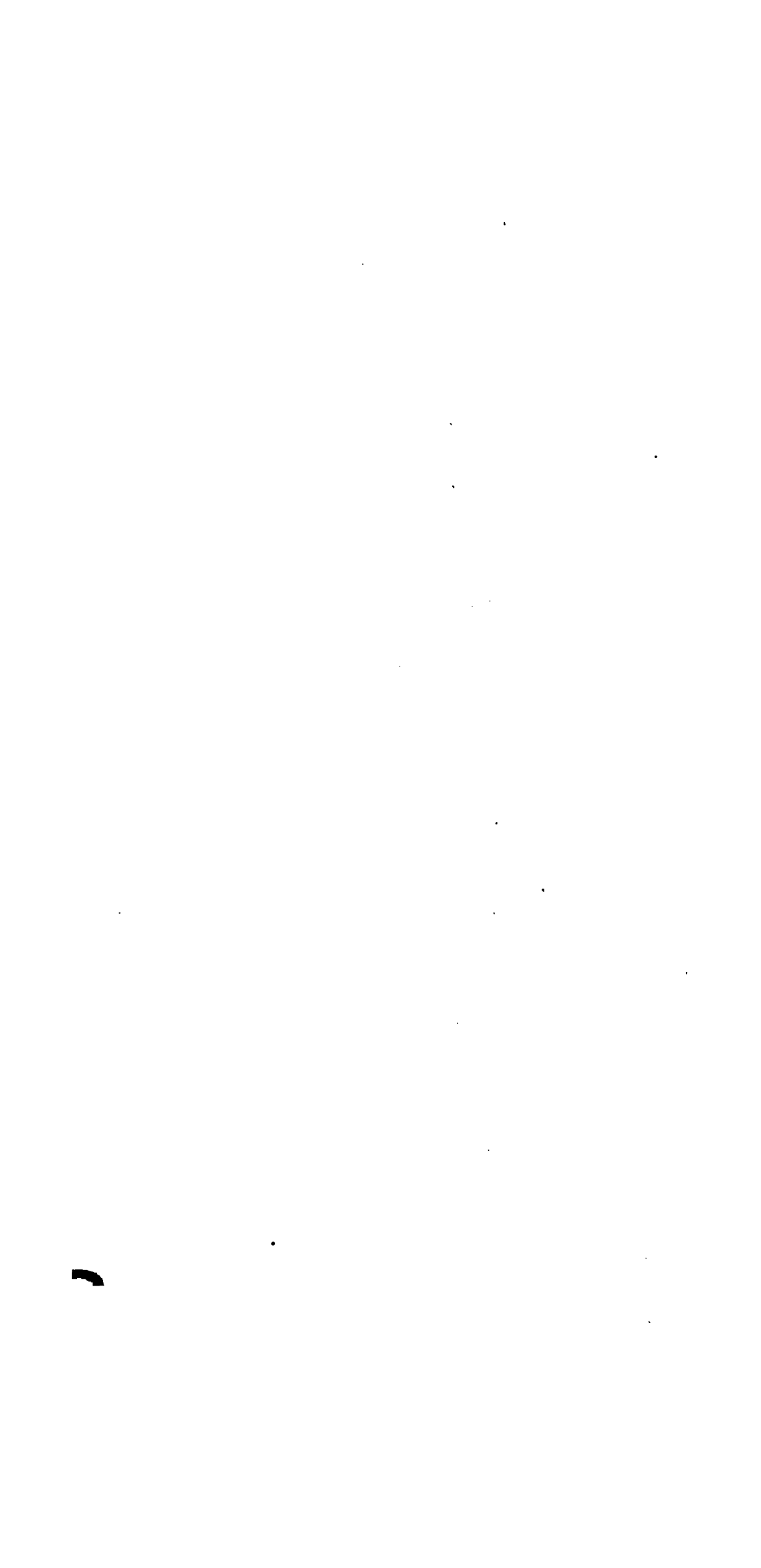
GYPSUM TWO PER CENT.

	Pounds.
24-hour neat	298
7-day neat	609
7-day 3:1 sand	241
Initial set: two hours.	
Final set: about eight hours.	
Boiling test: O. K.	

GYPSUM THREE PER CENT.

	Pounds.
24-hour neat	not hardened
7-day neat	403
No sand tests made.	
Boiling test: checked and warped.	

From these tests it appears that the best amount of gypsum to add to this cement is one per cent, that producing about the right time of initial and final sets for ordinary Portland cement requirements. The color of this cement was uniformly good. It is difficult to explain this, inasmuch as the raw materials contained very nearly the same amount of sulphur which so badly discolored the natural cement. A possible explanation may be this: In the natural cement there was a considerable excess of clay base and on that account any sulphur not burned out of the cement would have a tendency to form a sulphate with the iron and alumina. The dark ferrous sulphate would discolor the cement upon exposure to the air or on long storage of the cement this ferrous sulphate would change to the ferric sulphate. In the ferric state the discoloring action would not be so marked. This accounts for the change of color in the natural briquettes upon exposure to the air. On the other hand, in the artificial Portland mixture there would be practically no excess of clay base. Therefore, any sulphur not burned out would probably tend to combine with the lime, forming calcium sulphate which of course would produce no abnormal color.



THE GEOLOGICAL HISTORY OF
NORTH DAKOTA

BY

A. G. LEONARD

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INTRODUCTION.

It is the purpose of this chapter to present briefly the chief events connected with geological history of North Dakota. Many of the subjects which here receive only brief mention, such as the various rock formations, the Red River Valley and Lake Agassiz, the peculiar features of the badlands and their cause, these and many other topics are more fully discussed in the preceding chapters on the geology of southwestern and northeastern North Dakota, and the reader is referred to them for details. This paper has been prepared partly for use in the schools of the state in teaching physical geography and geology and partly that it may serve to give the general reader who may have little knowledge of geology, some idea of the ancient history of North Dakota.

The geological story of North Dakota is written in its rock formations, with their fossil remains of the animals and plants of the past. Through a study of these one may decipher with a large degree of confidence the ancient history of our state, and may trace the various changes it has undergone in the course of its gradual development from earliest geological time down to the present. The study is a fascinating one and brings before us movements of land and sea affecting the entire continent; the extinction of whole faunas and floras and the development of new plants and animals of higher and higher types; changes of climate from one of tropical warmth and moisture to the cold of the polar regions.

DIVISIONS OF GEOLOGICAL TIME.

A few words regarding the more important time divisions of geological history may help toward a clearer understanding of what follows.

The oldest rocks on the earth, those which are believed to have existed at one time in a state of fusion, belong to the Archean Era.

These rocks are mostly crystalline, that is, they are composed of various minerals which have crystallized out of the original molten mass, and they afford therefore almost no evidence of the existence of life at this early period. The granites are examples of these ancient igneous or crystalline rocks, which form the foundation for the more recent beds. Resting on this Archean basement in many places are rocks which bear every evidence of great age, having been much altered by heat and pressure, but are clearly of sedimentary origin—they are stratified and were formed under water by the deposition of sediments derived from land masses. They contain obscure traces of life, some undoubted remains of animals having been found in them, and the period of time during which these rocks were formed is known as the Algonkian Era.

The other great divisions of the earth's history, as recorded in the strata, are based on the life forms they contain. The earliest organisms were of simple structure and the same types existed all over the globe. There has been a gradual development of animals and plants by which they have become more highly organized, more complex in structure and more like modern types. Now that this succession of life forms has been made out it furnishes the means of determining the age of the beds forming the earth's crust and the order in which they were laid down. Certain fossils are found only in strata of a certain age, others are restricted to beds of a different age. It is thus possible by means of the organic remains contained in them to determine the succession of the formations and to correlate strata in widely separated areas.

The Paleozoic Era, or the time of most ancient life, was characterized by forms for the most part very unlike those of today; the modern types of animals and plants were almost entirely wanting and the vertebrates were represented only by strange, armored fishes and amphibians. The Paleozoic was followed by the Mesozoic Era or time of middle life when great numbers of enormous reptiles inhabited the land, the sea, and the air and were the predominating forms. During the last, or Cenozoic Era, signifying most recent life, modern animals and plants began to appear and the ancient types became almost extinct.

These three great divisions of geological history are in turn separated into shorter subdivisions or periods, each characterized by its own peculiar life forms. The Paleozoic Era, for example, is divided into the Cambrian, Ordovician, Silurian, Devonian and

Carboniferous periods. The Devonian is marked by the culmination of the fishes, which were present in great numbers and of large size, and during the Carboniferous coal-forming plants grew in great abundance and luxuriance.

It is possible from the study of the various characteristics of any rock formation to gain much information regarding the conditions under which that particular group of strata was formed. We know from the observation of present day processes, that sandstones are formed near the shores of sea or lake, where the coarser sediment carried by streams is deposited. The finer debris, such as mud and clay, will remain longer in suspension and will be carried far before settling to the bottom at a distance from the shore, to form a clay rock or shale. Limestone, which is composed of the shells of sea animals, or of the fragments and calcareous mud derived from these shells, is formed only in clear water—found usually far from shore, where the conditions are favorable for the growth and accumulation of these limestone-forming organisms.

Again, the fossils contained in the rocks tell whether they were formed in fresh or salt water—whether they were laid down in fresh water lakes or in the sea.

With these few words of introduction we pass to the consideration of the geological history of that portion of the North American continent known today as North Dakota.

The oldest part of this continent, that which was the first to be raised above the sea, was a U-shaped land mass, the two arms of the U enclosing Hudson Bay and comprising much of northeastern America. The nearest portion of this land area lay not far to the north and east of us, in northeastern Minnesota and Manitoba.

PALEOZOIC EVENTS.

At the beginning of the Paleozoic Era by far the greater part of our continent, with the exception of the above land, was beneath the sea and in this Paleozoic sea the rocks of the future continent were forming off the shores. As portions of the ocean floor were successively raised and made part of the original continental mass, the latter increased in size and extended its borders to the south, the east, and the west. Throughout all the vast periods of time represented by the Paleozoic, North Dakota and adjoining regions seem to have been under water. In this sea were deposited the limestones, shales and sandstones of the Cambrian, Ordovician, Silurian and Devonian, which outcrop about Lake

Winnipeg and in Minnesota, but are in this state deeply buried beneath more recent strata. Some of these beds were encountered in the Grafton well and indicate that during Cambrian and Ordovician time eastern North Dakota at least was receiving the deposits which later formed these rocks. The Paleozoic Era closed with the elevation and emergence from the sea of extensive areas and it is quite likely that this state shared in the general elevation and that it remained above the sea during a large part of the succeeding or Mesozoic Era, since any rocks belonging to any of the earlier periods of the latter era are wanting in this district. But during late Mesozoic time, or in the Cretaceous period, there was a great incursion of the sea over the North American continent, brought about by an extensive subsidence of the land. This vast sea stretched from the Gulf of Mexico north clear to the Arctic Ocean, covering much of the western interior region, including practically all of North Dakota.

DEVELOPMENT DURING THE CRETACEOUS.

Dakota Sandstone. For some time prior to this subsidence and invasion of the sea, North Dakota had been occupied by an extensive lake or lakes, in the waters of which a sandstone formation was deposited.

The fresh water beds thus formed constitute the Dakota sandstone, which has an average thickness of from 200 to 300 feet. This formation does not appear at the surface anywhere in the state but it is reached by many deep wells and is the source of most of the artesian water of this region. The porous sandstone is saturated with water and serves as a reservoir which furnishes a bountiful supply when it is reached by the drill. The Dakota sandstone has yielded an abundance of fossil leaves and some 500 species of plants are known from this one formation. These plants and the fresh water shells also occurring in the beds are an evidence of fresh water origin for the sandstone.

After the deposition of the sandstone beds the widespread subsidence, already referred to, followed, and the sea came in and covered all of North Dakota. The sediments which accumulated for many ages in this sea built up a series of shale, limestone and sandstone strata with a thickness of considerably over 1,000 feet.

Benton Shale. At the base of this rock series formed in the Cretaceous sea, and resting upon the Dakota sandstone, is the Benton shale, named from Fort Benton, on the upper Missouri in Montana.

where it is well shown. The Benton beds outcrop in this state only in the northeastern corner, in the Pembina Mountains. The latter form a wooded escarpment bordering the Red River Valley on the west for thirty or forty miles south of the international boundary. In this the rivers have cut deep valleys along which the shales of the Benton are well exposed. The outcrops are confined mostly to the Pembina and Little Pembina rivers. Elsewhere these shales are covered by more recent strata and are known only from their being struck in wells.

Niobrara Beds. Following the Benton formation and resting upon it is the Niobrara shale and chalk rock, named from its extensive development along the Niobrara river near its junction with the Missouri in Nebraska. The surface exposures of this rock are likewise confined to the stream valleys of the Pembina Mountain region, where the rivers have cut through the overlying beds and exposed the Niobrara. This formation is of special interest on account of its calcareous clay and cement rock, the latter used in the manufacture of natural hydraulic cement.

During Niobrara time there lived in the Cretaceous sea of this region countless numbers of microscopic animals which secreted a calcareous shell. It is the minute shells of these Foraminifera which, on the death of the organisms, fall to the bottom of the sea and accumulate to form chalk. The beds found in Cavalier county are not composed of pure chalk, since more or less clay is mixed with the calcareous shells, but the latter form a large part of the rock. Some layers of the Niobrara formation have a chemical composition which makes them a natural cement rock suitable for the manufacture of high grade cement and they are used for this purpose.

Fossil fish are not uncommon in the strata of this age and one in the roof of the Pembina Cement Company Mine has a length of five feet. Other fossils which have been found are the remains of the strange toothed bird (*Hesperornis*), a species of crocodile, and the great swimming reptile known as the *Plesiosaurus*, the latter being one of the rulers of the Cretaceous sea.

Certain calcareous beds outcropping along the Shyenne river at Valley City probably belong to the Niobrara formation.

Pierre Shale. Next above the Niobrara lies the Pierre shale, named from Fort Pierre, South Dakota, in the vicinity of which it covers a large area. This shale immediately underlies the glacial

drift over nearly one-half the state, covering most of the eastern half outside the Red River Valley. The rock is a black to a light bluish gray shale, very uniform in appearance over a large extent of country. There is an interesting occurrence of the Pierre shale on Little Beaver Creek in Bowman county, in the extreme southwestern corner of North Dakota, where it occupies a small area along the Montana line. Here the upper portion of the formation is exposed and it contains large numbers of calcareous concretions varying in size from several inches to five and six feet in diameter. These are very rich in fossils, about twenty species having been collected here, among them many beautiful ammonites with the mother-of-pearl sometimes perfectly preserved, besides the oyster and chambered nautilus.

Fox Hills Sandstone. The youngest and last marine formation to be laid down in the sea which covered this region during later Cretaceous times was the Fox Hills sandstone. This has a thickness of about 100 feet and is exposed at the surface at only a few points in North Dakota.

Rocks which probably belong to this formation occur overlying the Pierre shale in northwestern Bowman county, where they are seen along Little Beaver creek; they appear on the Cannon Ball river six miles above its mouth and also on Rice creek, a tributary of the Missouri river which enters it eight or ten miles north of the Cannon Ball river.

At the close of the Fox Hills epoch of the Cretaceous period the marine conditions, which had existed in North Dakota for many ages, came to an end through an elevation of the land and the withdrawal and the sea. This district has never again been invaded by the waters of the ocean.

Evidence has been found in the southwestern part of the state, along Little Beaver creek, that after the formation of the Fox Hills sandstone, the region was elevated above the sea and the land thus formed was subjected for a time to erosion. At several localities this old eroded land surface is shown and resting upon it are rocks much younger geologically than those immediately beneath,—rocks formed also under very different conditions, since they are fresh-water deposits and contain fossils quite unlike the marine beds of the Cretaceous. This old land surface separating the older beds below from the younger beds above is known as an unconformity.

FORT UNION BEDS.

These younger strata overlying the Pierre shale and Fox Hills sandstone cover the entire western half of North Dakota and constitute a formation with a thickness of 1,600 feet. In many respects this is the most important and interesting geological formation in the state, for in it occur the lignite beds, while its clays and sands have been sculptured into the picturesque badlands. For many years there has been some doubt as to the age of this thick series of beds but recent discoveries and the many fossils collected during the past few years have thrown much light on this. The formation is now referred to the latest of the great time divisions of the earth's history (the Cenozoic Era) and to the earliest stage of this era. It is known as the Fort Union, a name derived from the old fort at the mouth of the Yellowstone, near the site of the present town of Buford.

During Fort Union time, then, western North Dakota together with adjoining portions of Montana and Manitoba, was occupied by a large fresh water lake in which the sediments washed in by the rivers were deposited to form the beds of shale and sandstone. Certain portions of this lake became silted up from time to time and converted into marshes or swamps where vegetation grew luxuriantly as in the Great Dismal Swamp today. The trees and plants as they died year after year and accumulated under water, where they were protected from decay, were in course of time converted into the beds of lignite, so abundant in the Fort Union formation.

Some of the coal beds are of great extent. One is known to extend twenty-five miles in one direction and twenty miles in another, with an area of at least 500 square miles and a thickness of from five to sixteen feet. Another bed of coal has been traced thirty-six miles north and south and twenty-four miles east and west, and while its known area as shown from outcrops is nearly 900 square miles, it undoubtedly had an extent of 1,000 to 1,500 square miles. The thickness of this coal bed ranged from nine to fifteen feet and over.

The Fort Union formation is readily separated into three divisions by a marked difference in character and appearance. The upper beds are composed of rather dark gray sandstones and shales, with many brown, ferruginous, sandy nodules and concretions. The middle division is formed of light ash gray and buff shales

and sandstones which are remarkably uniform in color and appearance over extensive areas. The lowest member has a dark and somber aspect in striking contrast to the light colored beds above. It is composed of alternating layers of dark gray and brown shales and sandstones, containing many sandy nodules. The lower portion of this member contains no workable beds of coal.

All three divisions of the Fort Union are present in Billings county and are well shown in the Little Missouri badlands. The middle Fort Union appears also in the bluffs of the Missouri river from the mouth of the Yellowstone down as far as old Fort Clark, near the mouth of the Knife river. Below this point to the mouth of the Cannon Ball river and beyond the lower Fort Union occurs in the bluffs and the beds are well shown at the east end of the Northern Pacific bridge at Bismarck.

One peculiarity of the Fort Union formation cannot fail to attract the notice of even the most casual observer, and that is the vast quantity of burnt and fused clay which is seldom absent wherever there are extensive outcrops of the strata. This clay has been produced by the burning out of the beds of lignite, the heat thus generated having been sufficient to burn and often fuse the adjacent clays. This burning of the lignite has doubtless been going on for centuries and has resulted in the production of an astonishingly large amount of red clay. Bands of this material have been traced fifteen and twenty miles, and except at a few points where the coal is still intact, none of the seam has escaped the fire along its outcrop.

The Fort Union strata are also remarkable for the variety and abundance of their fossil plants which are represented mostly by leaves. Nearly 400 species are known from this one formation and the leaves are often beautifully preserved, showing the delicate venation in great perfection. One of the most common trees of Fort Union time was the poplar, many varieties of which are found. Another tree growing in North Dakota at that time was the Sequoia or redwood, related to the giant trees of the Pacific coast. Water lilies and ferns were also present.

In addition to its plant remains the Fort Union contains many fossil fresh water shells, these being very abundant in some localities. But its most interesting fossils are the bones of the gigantic extinct land reptiles known as dinosaurs. During Fort Union time these strange animals lived in large numbers in North Da-

kota, Montana and Wyoming, and their huge and clumsy bones were buried in the lake deposits of that period. Among the most common was the massive Triceratops, with its enormous skull which projected backwards over the neck in a cape-like extension, and three horns, a stout one on the nose and a pair of long, pointed ones on the top of the head. The bones of Triceratops are found in southern Billings county and fragmentary dinosaur bones have also been found by Dr. T. W. Stanton on the Missouri river between Mandan and the mouth of the Cannon Ball river.

To the Fort Union formation belong the high grade fire and pottery clays of the western part of the state. These very pure and white fire clays cover an area of approximately 4,000 square miles, lying between the Missouri and Little Missouri rivers. They occur at elevations of from 2,450 to 2,600 feet above sea level, and are confined to the tops of the higher ridges and divides. Their maximum thickness is about 150 feet. These fire clays are remarkably uniform over the entire district and their white color makes them conspicuous wherever they are exposed.

THE BADLANDS.

It is in the strata of the Fort Union that the famous badlands have been eroded. The true badlands, that is, the very rough areas that are difficult to travel through, are confined to the vicinity of the streams. Back from these six or eight miles the land is a rolling plain and is not "bad" in the sense probably meant by the old French term "*mauvaises terres*" originally applied to the region with reference to its being a land bad for the traveler.

Though by no means confined to that stream the badlands are typically developed along the Little Missouri and Medora is located in their midst. The soft clays and sands of the Fort Union formation have been carved by running water into a multitude of steep-sided hills, isolated buttes and an endless variety of fantastic forms. The change is abrupt from the gently rolling plain to the strip of badlands bordering the river and forming a belt ten to twenty miles wide, within which the effects of erosion are so strikingly seen on every hand. This erosion is greatly facilitated by the sparseness of the vegetation, the slopes being almost bare of verdure, and by the softness of the rocks. Though the region is one in which the rainfall is light, every shower is highly effective in washing away the unconsolidated sands and clays. The slopes,

the sides of every hill and butte, bear the marks of the last shower. They are grooved with countless tiny channels formed by the little rivulets of water which poured down the slopes. Each rivulet gathers up its load of detritus and carries it on to the main stream. The river has its numerous tributaries and these in turn have their branches which are ever working back into the land. And thus what was formerly a comparatively level plain, similar to that about Dickinson is now carved into the weird and picturesque badland topography which is described and figured in all text books of geology.

Beauty and variety are added to the landscape by the diversity of color. The colors are arranged in broad bands along the faces of the bluffs—gray, yellow, black and red of every shade and tint, together with browns and pinks. The banded and many hued bluffs, buttes, domes and pinnacles are a characteristic feature of the badlands and increase their attractiveness from a scenic point of view.

OLIGOCENE BEDS.

At several localities in the state there are remnants of a formation still younger than the Fort Union, and resting therefore upon the latter. This belongs to that division of the Cenozoic Era known as the Oligocene, and the beds of this age are found on top of Sentinel Butte, they form White Butte in southern Billings county, and occur in the "Little Badlands" of southwestern Stark county.

Sentinel Butte enjoys the distinction of being the highest point in North Dakota, having an elevation of 650 feet above the plain at its base, and 3,350 feet above sea level. Occupying thirty or forty acres on its summit there are beds of white marl and limestone about forty feet thick, which must have been formed in a fresh water lake covering a considerable area in the western part of the state during Oligocene time. The strata on top of the butte are merely the remnants of a once widespread formation which has undergone extensive erosion and has thus been very largely removed except at a few localities such as this which were favorable for its preservation. In the waters of this Oligocene lake lived large numbers of small fish whose remains have been perfectly preserved on the thin slabs of white limestone.

White Butte is so called from its chalky whiteness, though the rocks of which it is formed are not limestones but calcareous clay

and sand, together with a coarse conglomerate composed of water-worn pebbles of volcanic rock which must have been brought by streams hundreds of miles from the Rocky Mountain region or the Black Hills.

The Oligocene beds are here 300 feet thick and in them Mr. Earl Douglass, of the Carnegie Museum of Pittsburg, several years ago collected the bones of the three-toed horse (the ancestor of the modern horse) and the rhinoceros. The geological collections of the University contain the skull of an extinct cud-chewing mammal from these same strata.

Rocks of this same age are also found in the so-called Little Badlands of southwestern Stark county and the beds here have yielded the remains of many extinct mammals.

These Oligocene beds are thought to be in part lake deposits, as already stated, and in part river deposits. The lack of uniformity, the cross-bedding, and the coarseness of the materials of some parts of the formation are probably the result of deposition by rivers, while other portions were apparently laid down in the more quiet waters of a lake. Whether the beds of the three North Dakota Oligocene areas were deposited in one large lake covering a considerable portion of Billings and Stark counties, or whether they were accumulated in several small lakes, it is impossible to say.

The disappearance of the Oligocene lake or lakes was followed by a long lapse of time during which no new rock strata were formed in this region but on the contrary erosion was actively going on throughout the entire area. The land surface was attacked by the forces which are ever at work to reduce it to sea level, running water being the most effective of these agencies, and many hundreds of feet of strata were swept away by the streams. The numerous high buttes which rise above the surrounding country and form conspicuous features of the landscape, bear indisputable testimony to the enormous amount of erosion which has taken place, for they are formed of horizontal beds of clay and sand which were once continuous over the entire region, but have been almost wholly carried away through the work of running water. Such buttes as Sentinel, Bullion, Black, Rainy and scores of others are merely the remnants of these beds and can only be accounted for by the erosion and reduction of a land surface which must formerly have been several hundred feet higher than the highest of these buttes. The thickness of strata thus removed over extensive areas

in western North Dakota could not have been much less than 1,000 feet, and it may have been more. This included almost all of the Oligocene beds and some 700 feet and over from the upper portion of the Fort Union formation.

THE GLACIAL PERIOD.

At no time in its geological history has the state undergone more important, far-reaching or more significant changes than during the time just preceding the present or Human Period, that is, during the Glacial Period. The climate now changed to one of Arctic rigor and for some thousands of years it was like that of the polar regions. Immense glaciers or ice-sheets, comparable to those found today in Greenland and the Antarctic region, but many times larger, moved down from the north and buried all the northern part of North America under thousands of feet of ice. There were three centers of movement for these great continental glaciers, one east of Hudson Bay, one west of the same bay and the third in the Canadian Rockies. The Keewatin and Labrador ice-fields moved out to the north, south, east and west. South of Hudson Bay they united and invaded the United States as one. New England was completely buried by ice, as were portions of New York and Pennsylvania. It extended south to the Ohio river at Cincinnati, and to southern Illinois and Indiana. West of the Mississippi the line marking the limits of the glacier passes near St. Louis and Kansas City, then curves northward and follows in a general way the course of the Missouri river to Montana; here it turns north and crosses the international boundary a short distance east of the Rocky Mountains. All of North Dakota except several counties in the southwestern corner was covered by the ice-sheet and its surface features were profoundly modified by it, while its soils are largely of glacial origin, directly or indirectly.

When after some thousands of years the continental glacier withdrew it left behind a deposit of greater or less thickness which forms a mantle concealing the bed rock from view. This peculiar glacial deposit is known as drift and it is composed of clay, sand, gravel and boulders mingled together to form a heterogeneous mass. The chief constituent is commonly a stiff blue or gray clay through which are scattered numerous pebbles and boulders of granite or other igneous rock. One very noticeable feature of this boulder clay or till, as it is called, is that very many of the boulders and pebbles are unlike the bed-rock of the vicinity. They have

been transported by the ice from localities often hundreds of miles distant, and while being moved along on their journey many of the pebbles and boulders were smoothed, polished and scratched on one or more sides.

The thickness of the drift varies within wide limits, being all the way from a few feet to several hundred feet. In the eastern part of the state it is shown by wells to be commonly from 200 to 300 feet thick and it is probable that these figures also apply to the central part of the district. Wells pass through 220 feet of drift at Fargo, 250 feet at Casselton, 298 feet at Grafton and at Grand Forks a well penetrated 380 feet of lacustrine deposits and drift before reaching bed rock.

That there were several periods of glaciation during which the continental glacier advanced far to the south, followed by interglacial periods when the ice-sheet retreated and left the surface free to be covered once more with vegetation, is clearly shown by the different drift sheets, some of which are much younger than others. Named in the order of their age from oldest to youngest these are the sub-Aftonian, Kansan, Illinoian, Iowan, Earlier Wisconsin, and Later Wisconsin. Between the periods of ice invasion when these were deposited there were times of retreat and these interglacial intervals are marked by vegetable accumulations representing old forest beds and soils, often many feet in thickness, and by heavy deposits of gravel and sand laid down by the streams flowing from the melting ice.

There is considerable evidence that only the later of these drift sheets are present in North Dakota, namely, the Earlier and Later Wisconsin, although some geologists have thought the Kansan drift also occurs in the state.

During the final retreat of the ice-sheet northward it paused from time to time and its end remained stationary, often for long periods. During these pauses in its withdrawal, terminal moraines were heaped up by the ice, the materials brought forward to the end of the glacier accumulating and piling up there in very irregular fashion. Each of these moraines consists of a single ridge or a belt of ridges and hills varying from or two to fifteen and even twenty miles in width. The individual hills sometimes rise 100 to 200 feet above the general level of the country, or again, they are low and gentle elevations. Among the hills are many hollows and depressions which are frequently occupied by lakes and marshes, so character-

istic of terminal moraines. There are as many as eleven of these moraines in the eastern half of North Dakota and their presence adds much to the roughness of the surface. These hilly belts often form conspicuous topographic features and can be seen from a distance of many miles.

The outermost and the best developed of all these moraines is known as the Altamont moraine, which forms a conspicuous belt of irregular hill and hollows ten to fifteen miles wide. The margin of the ice-sheet must have remained stationary here for a long time to allow the rock debris carried by the glacier to accumulate in this great stretch of morainal hills. This Altamont moraine has been traced across the state from north to south; it traverses Ward county from northwest to southeast about thirty-five miles west of Minot, turns south through eastern Burleigh county, crosses northeastern Emmons and after making a loop to the east into Logan and McIntosh counties, again enters the southeastern corner of Emmons, whence it continues into South Dakota. The Northern Pacific railroad crosses the Altamont moraine between Driscoll and Sterling.

The drift outside is very little older in appearance than that inside the moraine, and is strikingly different from the Kansan as it appears farther south in Iowa and Kansas. For this reason it is believed to be Earlier Wisconsin, and the drift within the moraine is probably Later Wisconsin.

The continental ice-sheet is the cause of the wide-stretching, gently rolling to rough drift plain with its numerous lakes and imperfect drainage which occupies nearly two-thirds of the state. Its effects are everywhere apparent and unmistakable. Before its advent the area was undoubtedly more uneven than at present, since it was an old land surface which had been roughened by the long continued erosion of streams. The ice-sheet modified all this and tended to level up the region by wearing down the hills and ridges and filling the valleys with debris. Upon its retreat there was left the heavy mantle of drift which conceals from view the old preglacial surface. It is this drift which forms the rolling, and in places rough, plain stretching westward from the Red River Valley clear to the Montana line north of the Missouri, and extending fifty miles or more west and south of that river.

The broad, flat plain known as the Red River Valley was also formed through the agency of the ice-sheet. The valley consti-

tutes a well marked depression extending south from the basin of Lake Winnipeg as far as the South Dakota line and bordered on the east and west by land rising 400 to 600 feet above the bottom of the valley. Toward the close of the Glacial Period the great body of water which has been named Lake Agassiz occupied this valley and extended far north into Manitoba, having an area of 110,000 square miles, or more than the combined area of the Great Lakes. The lake came into existence when the continental glacier, during its retreat northward, gradually uncovered the broad depression of the Red River Valley, and formed an immense dam of ice at the north which prevented the drainage of the melting ice from finding an outlet in that direction. As the ice-sheet retreated the lake was gradually extended and continued to increase in size until its maximum area was attained. The rivers emptying into Lake Agassiz carried large quantities of sediment which were distributed by the waves and currents and settled to the bottom to form the sandy clay or loam of the lacustrine deposits. When the ice finally disappeared from the Lake Winnipeg basin, Lake Agassiz was drained and its bottom was left to form the level and fertile plain of the Red river.

That but a short time, geologically speaking, has elapsed since the close of the Glacial Period is proved by the fact that this plain and the drift plain occupying so large a part of the state have suffered very little erosion. The disappearance of the continental ice-sheet has been of such recent date that the streams have not had time to dissect and roughen the surface with their valleys, as they have done in the unglaciated, southwestern corner of the state.

THE BOTTINEAU GAS FIELD

BY

JOHN G. BARRY

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During the past year and a half several discoveries of natural gas in Bottineau county and eastern Ward county have caused considerable excitement. The first discovery was made at the Parker farm about nine and a half miles south of Westhope on July 3, 1907, when gas was struck at a depth of 178 feet while drilling a well for water. Since that time many wells have been drilled for gas in the same region and a number of them have been successful. A preliminary investigation of the region was made early in September, 1908. Since the time possible for this work was very limited, only the main facts in regard to the field were obtained.

The wells drilled in the vicinity of the Parker farm pass through the glacial covering and cut a gas bearing sand at depths ranging from 154 to 176 feet. Four wells at this place have shown good flows of gas, while three others drilled to the north, toward Westhope, have been unsuccessful. A pressure exceeding 100 pounds per square inch and a flow of two million cubic feet per day is reported for each of the successful wells. The Great Northern Oil, Gas and Pipe Line Company, which has been carrying on prospecting at the Parker farm, has drilled a deep well in hope of striking a deep seated body of gas. At the time of the visit to this region this deep well had reached a depth of 1,180 feet. An oil well borer of the usual American type with a derrick built on the ground was in use. (Plate XXIX). The boiler was fired with gas from a nearby well. The following strings of casing were in place: 175 feet of 10-inch, 600 feet of 8-inch, and 995 feet of 6-inch, all starting from the surface. On September 11, 1908, this well showed the following section:

	Feet	Inches
Soil	2	
Yellow clay and gravel	30	
Blue clay	122	
Gravel with sand below (no flow of gas)	16	
White slate	35	
Black sand seam (Pierre?)	3	
Soft blue shale (caving) (Pierre?)	242	

	Feet.	Inches.
Black "slate" (Pierre?).....	50	
Blue shale (caving) (Pierre?)	205	
Yellow hard rock (limestone) (Niobrara?).....	..	5
Blue shale	145	
Sandy shale	10	
Blue shale to bottom (Benton?)	320	
	1,180	

Oil seepage is reported in the common wells of this vicinity, but this is probably due to decomposing organic matter in the drift.

In the vicinity of Mohall there are two wells that have yielded gas. They are about seven miles west and north of the town, and about 26 miles west of the wells at Westhope. A generalized section of these wells is as follows:

	Feet
Yellow clay	20 to 25
Blue clay	200
Blue shale including streaks of black sand and coal (?)	70 to 80

Gas was reported to occur at a depth of 225 feet, at the junction of the blue clay and blue shale, and showed a pressure of 25 pounds per square inch. It was also claimed that further drillings gave gas at 340 and 470 feet, but this was due probably to loose casing with gas leaking down and around the bottom from the occurrence at 225 feet.

Since the visit to this region gas has been reported as having been struck at the following places: Maxbass, sixteen miles southwest of Westhope; Lansford, ten miles southeast of Mohall; and at the McCaslin farm, fourteen miles southwest of Mohall, and five miles west of the Parker farm, at a depth of 200 feet.

The sand in which the gas is found varies in thickness, in most cases, from 16 to 20 feet. It is medium fine grained, rounded, and of a greenish black color, due to an admixture of decomposing carbonaceous matter.

An analysis of the gas made by Professor E. J. Babcock, of the University of North Dakota, shows the following results:

	Per cent
Hydrogen	0.5
Methane	82.7
Ethylene and other illuminants	0.2
Carbon monoxide	1.2
Oxygen	3.0
Nitrogen	12.4
B. T. U. (calculated) 886 per cubic foot.	
The oxygen and nitrogen are probably in the form of air.	



Boring for natural gas nine miles south of Westhope, Bottineau county.
The boiler is fired by gas.



The gas has a slight blue color, when blown off at the well. From the sample analyzed this appears to be a dry gas, and would doubtless be serviceable for power as well as for heat and light. For lighting purposes, it would probably give the best results by use of the mantle. From the analysis and heating power, it will be seen that this is a valuable gas for household and industrial uses. It has an odor similar to that of gas driven off from North Dakota lignite by distillation, and it is probable that the carbonaceous matter of the gas-bearing sand originated either from the erosion of lignite beds, or from the same kind of vegetable matter as the lignite.

In general, a flow of gas is struck in this region after penetrating the glacial drift, at a depth varying from 154 to 200 feet. The gas is contained in a carbonaceous sand whose thickness is between 16 and 20 feet. With the exception of the two wells at Mohall and the one at Lansford, the gas occurs within the known area of glacial Lake Souris.

It is impossible at present to definitely outline the possibilities of the area. The gas is now being used locally in farm houses and it is proposed to pipe it to Westhope for use there, and later to some of the other surrounding towns. Just how large a quantity of gas is present in the area is uncertain. Further prospecting should be carried on in this area and careful records kept of all the wells, and further analyses and accurate determinations of pressure and flow should be made. Should this prospecting show a considerable area of gas bearing sand, it is quite possible that with judicious use this area might supply the local demand for light, heat and power for a number of years.

Origin.—It has been previously pointed out that most of the wells of this area which have been productive are situated within the area of glacial Lake Souris, and that the gas occurs in a layer of sand immediately underlying the drift. Upon the recession of the ice sheet from the Coteau du Missouri a glacial lake known as Lake Souris was formed, lying between the Coteau and the southern border of the ice sheet.¹ The western border of this lake extended from between Hargrave and Elkhorn, Manitoba, on the Canadian Pacific Railway, in a southerly direction to the international boundary at T. 164, R. 82, (United States), and thence south to the vicinity of Minot.

¹Upham, Monograph XXV, U. S. Geol. Survey, p. 267.

From that point the lake shore extended in a southeast direction to the southwest corner of T. 153 R. 80, northeast to the vicinity of Rugby, and north to Dunseith; it followed the foot of the Turtle Mountains to the west and north; and from the northern part of T. 1, R. 18, (Manitoba) ran in a northeasterly direction to Killarney and Pelican lake. The lake occupied the basin of the Mouse river from near the southern portion of its loop in North Dakota, to its "elbow" in Manitoba, where the stream changes from a southeast to northeast direction about eighteen miles south of Brandon. The lake stretched north along the Assiniboine to a point a short distance above the mouth of the Qu'Appelle river. Its extent eastward was limited and its shore line deeply indented by the Turtle Mountains. In a north-south direction the lake extended 170 miles, and north of the Turtle Mountains it had a width of about seventy miles. This lake was at first drained to the south by the Sheyenne river, later to the north and east by Pelican and Rock lakes and the Pembina river, and finally to the north by the Assiniboine river, which is the present drainage outlet for the area.

Another important fact in regard to this region should be mentioned. The Coteau du Missouri lies about fifty miles to the southwest of Upham, in northern McHenry county, and runs in a northwest-southeasterly direction. The Turtle Mountains lie about twenty-five miles to the northeast of Upham. Both the Coteau du Missouri and the Turtle Mountains have a considerably greater altitude than the region under consideration. It is known that the shale beds of the Coteau, underlying the glacial drift, are several hundred feet higher than the surface to the east, and these same shales occur in the Turtle Mountains, but are absent from the intervening area. Undoubtedly the Coteau and the mountains were at one time continuous, but the strata of the intervening area have been removed by erosion.

It is thought that the ice-sheet did not change to a marked degree the larger preglacial topographic features, but that its erosive action was limited mostly to wearing down the smaller elevations and partly filling the pre-existing valleys with its debris, and thus creating a surface of more uniform contour. It is not likely that the ice-sheet would erode to any great extent so wide a strip of country as that separating the Coteau du Missouri and the Turtle Mountains. The latter, then, were separated from the Coteau prev-

ious to the advent of the ice-sheet. Considering the course of the Coteau du Missouri, and the Souris and Sheyenne rivers, it is reasonable to suppose that previous to glacial time there lay to the north and east of the Coteau a principal drainage area which had a northwest-southeast course, and which probably drained to the south and east.

Whether this drainage was occupied by a freely flowing river or by a large lake is not known. It is certainly reasonable to suppose that there was deposited throughout the region a considerable amount of detrital material with an admixture of organic matter, probably of vegetable origin. Upon the advent of the ice-sheet part of this detrital material was no doubt eroded, but some of it could easily be covered by the relatively thick and impervious drift deposit. Upon the decomposition of the organic matter the preglacial debris would act as an excellent gas reservoir. The occurrence of this gas-bearing sand over so wide an area leads to the belief that this preglacial drainage channel was perhaps occupied for a time by a lake.

Another possible source for the gas is the organic matter of the shales underlying the drift and gas-bearing sand. The gas may have formed in the shales and collected in the overlying sand.



GOOD ROADS AND ROAD MATERIALS

BY

W. H. CLARK

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HISTORICAL.

The earliest knowledge we have of road building is in Egypt. Some recent excavations near the pyramids have brought to light the fact that a metal roadway was constructed from the Nile to one of the pyramids. The excavations have not been carried far enough to determine how the road was constructed. We have a better knowledge of the roads built in the Orient by Darius. Long roads were built radiating out from his capital city, Susa. These were mere trails leading from Susa to the capitals of the twenty provinces which were under the jurisdiction of this great organizing monarch. The purpose of the roads was to facilitate rapid communication between the king and his satraps in the provinces. While it is true that these roads were chosen with much care, there was very little done in the way of what we now call road building. The best geographical position was chosen, and obstructions were removed and overcome. Further than this there was no evidence of road engineering. This was about five centuries before Christ. It was not until a late period in Roman history that road building was considered a problem for the engineer.

The earliest notable piece of permanent road building we know of in Italy was begun by Appius Claudius, 312 B. C. From this time down to and including the Roman Empire thousands of miles of roads were built. The Roman roads covered Italy as a network and extended to all parts of the Roman Empire. They were built by soldiers and slaves under the direction of an engineer, and it was then that roadmaking was put upon a scientific basis. Since then road construction has been considered work for the engineer, though after the method and material have been determined upon every farmer becomes in a sense a road maker.

VALUE OF GOOD ROADS.

A cursory perusal of the reports of railroad commissioners and of the data compiled by the Departments of Agriculture would

convince the most skeptical theorist that the agricultural and transportation interests of the United States overshadow in importance the manufacturing and all other interests combined. The question of our success as a nation depends not on what we can make, valuable as this element is, but on what can be raised from the soil and transported to the consumer at a cost that will not be prohibitive. Therefore it follows logically that our national importance hinges in a large measure upon the condition of the highways throughout the country; for, if crops be abundant, labor plentiful, and money for transportation can be had at reasonable rates, but the roads cut off communication from farm to shipping points, the price of the produce becomes abnormally high and what ought to become a public benefit becomes a national calamity.

The lines of inquiry in one experiment showed that the average length of cartage over country roads was slightly over twelve miles, with an average weight of a little over two thousand pounds per load, and a consequent cost of about twenty-five cents per mile. Although these figures are correct for upward of a thousand counties throughout the United States, they would be modified by complete data covering the whole country, but they are indicative of the general condition and cost to the farmer of transporting his produce. We would not for a moment permit the railroads of the country to charge such an exorbitant rate, but the grangers and others have for years acquiesced in a practice that has robbed them of the comforts and in many instances of the necessities of life.

On good roads heavier loads can be drawn faster and the difference between the selling price of the produce when carried in a wagon over a smooth road for an hour and the price of the same product transmitted over a rough road for three hours is oftentimes the difference between profit and loss. It has been mathematically demonstrated and shown to the eye by the use of highway maps that the improvement of from eight to sixteen per cent of the total highway mileage of the state, being the main highways which follow the valleys or are arbitrarily established in level sections, will leave no farm further than five miles from the main highways. Therefore, the improvement of a comparatively small percentage of the total mileage is of a certain and positive value to the entire agricultural interests of the state. The following table shows the cost of hauling products five miles, which gives readily to the eye

the reason why a longer haul is not profitable unless the products transported be of greater than ordinary value as compared to the usual product carried.

\$1.25 will haul a ton	Cost per mile
5 miles on a common road	\$0.25
12½ to 15 miles on a well made road .....	.12
25 miles on a trolley road .....	.05
250 miles on a steam road .....	.005
1,000 miles on a steamship .....	.0012

Stated briefly, the economies effected by good roads are:

1. Reduction of the number of horses kept for hauling. 2. Reduction of wear and tear on horses. 3. Saving of repairs to wagons and harnesses. Considering the first of these, in 1900 there were 314,493 horses in North Dakota. Good roads would mean that this number could be decreased one-fourth. It can be seen that a large saving would be effected. Farmers would not need to keep more than the usual number required for the regular work on the farm. In addition to the hauling done directly by the farmers themselves, there is a large amount done by dairymen, freighters, ranchers and others who keep horses solely or principally for the purpose of hauling on the roads and they would certainly require fewer horses if the roads were improved. The load which can be drawn by a horse depends upon the grade and the surface of the road. The following table shows the relative number of horses necessary to pull an equal weight on various level surfaces:

Surface	Number of horses
Iron rails	1
Macadam	5⅞
Earth	20
Sand	20

Another way in which good roads will increase the hauling capacity of a horse is in the fact that much lighter wagons could be used than are now required to withstand the jars and shocks of our bad roads, and more of the horse work would go directly into hauling the load and less into merely hauling the dead weight of the wagon.

Secondly, the wear and tear on the horses is a very serious item to farmers, both by reducing the life service of the animal, and also by increasing the necessary food. Figures on this point are very difficult to make accurately, but everyone having the care of horses will recognize that the saving will be considerable.

Thirdly, there is a great saving in the repairs to harness and wagons effected by good roads. Here again it is difficult to produce accurate figures, but it has been estimated that the saving in the repair bill will be about one-third.

INCREASE OF LAND VALUE.

We see then that the economic saving in good roads by the reduction in the number of animals, the wear and tear on horses, and repairs to wagons and harnesses, is of great importance, yet there is another important consideration which we must not overlook. This is the increased value of land. It is true that we cannot get any information from North Dakota on this phase of the subject for not much road building has been done. But much evidence can be secured from the eastern states, all of which shows an advance in the price of land as soon as the roads are improved. In New York a hard road was put in at a cost of \$1.50 per acre of the adjoining farms and the land increased in value from \$20 to \$30 per acre. In Connecticut there are three towns in a line, the outer two of which have improved their roads with the result that their land values are fifty per cent higher than those of the middle town. In Maryland a large number of farmers were asked their opinion on this subject and the universal answer was that the lands would increase in value.

Before leaving this phase of the subject of the appreciation of land values by good roads, it must not be overlooked that such roads increase land prices by increasing the demand for the land. For what farmer in changing his home would not, other things being equal, move to a region of good roads rather than to one of bad roads. The reverse is true, and bad roads tend not merely to keep off prospective settlers but they even drive away those who have already made a home in the neighborhood, and thus depreciate land values.

This line of inquiry concerning the importance and indispensability of good roads in every community, conducted by government and state, has shown the present prohibitive cost of cartage and the great necessity of hauling at a cheaper rate. Nearly all are convinced of these facts. That which is more to the point at this time, and which is extremely more valuable to farmers and all concerned is to indicate how this prohibitive tax of hauling may be decreased. Information regarding this may come from a num-

ber of sources, including the North Dakota Geological Survey, which can furnish valuable data. It has been the purpose of the Survey in its field work to locate road materials and examine their quality. There is a wide variance in the gravels of the state. It is not only necessary that farmers and other road builders know where the most available road material is located but money may be saved in many instances if a poor worthless material is avoided and a better one substituted.

The study of road metals and road surfacing materials in North Dakota has been greatly neglected, both because North Dakota, in common with South Dakota, Nebraska, and Kansas has a naturally good road surface; and because there has not been any public demand until recently for such information.

RELATION OF ROADS TO TOPOGRAPHY AND GEOLOGY.

The relation of the topography, geology and climate of North Dakota to the roads is not so complex as in many states. For our purpose North Dakota may be divided into three parts. First, the river valleys, which include the Missouri, Mouse, James, Red and their tributaries; second, the glaciated area of the state exclusive of the river valleys; and third, the unglaciated portion in the southwestern corner of the state. The latter includes Billings, Bowman, Stark, Hettinger and Adams counties. The purpose of this classification is two-fold, in that these subdivisions indicate the material of the natural roadbed, and also the gradients.

The River Valleys. The natural road surface of the Red River Valley is typical of the other river valleys of the state. It is a black sticky loam. When wet it is extremely tenacious and when dry it bakes very hard. The indications all point to the probability that if the road surface was properly smoothed and crowned after each rain it would dry into an ideal roadbed. But the fact still remains that it is always heavy and sticky when wet. This, then, demands that the road should be surfaced. Now the Red River Valley is poorly situated with reference to road metals. The only road surfacing materials are found along the western portion of the valley, in the old shore lines of Lake Agassiz, which consist of sand and gravel. These beaches commence approximately at the southeastern corner of North Dakota and run northwest for seventy-five miles, to T. 133, R. 54 W; thence they extend nearly due north. These old beaches which mark the former shore-line

of Lake Agassiz contain all the road surfacing material for that part of the Red River Valley which lies in North Dakota. The beaches of themselves form a natural highway, no surfacing is required, and the grade in passing northward is only two hundred feet in three hundred miles; or two-thirds of a foot per mile. Practically no stone is found throughout this entire area, except the gravel of the beaches.

The beaches, which are approximately parallel, vary in number from six to fifteen, and occupy a strip one to six townships wide. They include an area of at least four thousand square miles. All of the roads in this area are so favorably located that they can be cheaply surfaced. Not all the material in these beaches is suitable for road surfacing, but there is an abundance of excellent gravel. At the southern end of Lake Agassiz, where the shore lines enter North Dakota, there is a delta of large area, formed by the Sheyenne river. The surface from a depth of from fifteen to forty feet is composed of delta sand and gravel. It is a plain sloping gently eastward and crossed by the Herman and Norcross shorelines, and in part by the Tintah and Campbell shores on its eastern and southeastern border. The front of this delta begins at the Herman beach in the south tier of townships in Cass county. From the Maple river it extends eastward eight miles, passing Leonard, and thence southeasterly twenty-five miles. Its greatest length fifty miles from southeast to northwest and its greatest width is thirty miles. It covers an area of 800 square miles. Large tracts of this delta are channeled by the winds and heaped up in dunes which rise to a height of twenty-five to one hundred feet or more. Most of the delta is composed on the surface of coarse sand, though gravel deposits are found in places. The four beaches which border this delta, three on the east and one on the west, furnish an abundance of gravel for road surfacing material. As this area is crossed by five railroads, the sand and gravel are readily available.

The road problems which exist on this delta are the opposite of those found in adjacent parts of the Red River Valley. Here the rainfall readily soaks into the soil leaving it dry and sandy. The cheapest method of preparing such a road surface for traffic would consist in surfacing it from the gravel beds. On the other hand the sand and gravel of the delta would be serviceable in preparing the roads of the muddy valley to the east. It has been

determined by a large number of experiments all over the United States that sand and clay mixed to the point of saturation make a hard and durable road surface. The Sheyenne delta, then, will not only furnish gravel for its own roads but it is an abundant source of supply for sand and gravel for a large area between it and the Red river. The grades on this delta, as in the Red River Valley, are imperceptible.

The geological and topographical conditions which we find on the Sheyenne delta largely prevail on the Elk Valley delta. The latter commences in T. 156, N., R. 56 W., and ends in T. 147 N., R. 53 W. It is about sixty miles from north to south and has an average width of nine miles. This extensive delta of sand and fine clayey silt was brought into Lake Agassiz by the glacial river of the Elk Valley. It is traversed on its eastern border for twenty miles by the Tintah beach which contains an abundance of sand and gravel highly desirable for road surfacing. This delta is also traversed by the lower Herman and Norcross beaches which also contain suitable road materials.

In the extreme northern part of the state, along the shore-line of Lake Agassiz, is found the delta of the Pembina river. This lies mostly in T. 162 and 163 and R. 56 and 57. In the gravel of this delta the pebbles of some beds are mainly Cretaceous shales, of others mostly limestone, and of others granite and gneiss. In the aggregate these three classes have a nearly equal representation, and they are commonly intermingled in the same beds. White quartz and moss agate are frequent, and bits of silicified wood occur rarely. All of the constituents of these gravel beds make excellent road surfacing material with the exception of the argillaceous shale, which is soft and when ground up by the attrition of wagon wheels becomes slippery.

The three eastern beaches, namely, Burnside, Gladstone and Ojata, are largely clay mixed with a little gravel and sand. These will not make good road surfacing material as they have too large a proportion of lacustrine silt. The Emerado beach which runs parallel to these on the west is mainly composed of sand and gravel of a high road surfacing quality. Extending as it does for a long distance through the valley with mud roads on both sides of it, its sand and gravel are available for many miles of highway. It crosses the northern boundary of North Dakota in the north-eastern corner of T. 164, R. 55, and extends southeast to Cava-

lier. From that point it passes in a southerly direction to Crystal; from Crystal southeasterly to Emerado and Buxton. In sections 2, 11, 12 and 13, T. 162, R. 55, the Emerado beach widens out into a sand deposit. The Campbell beaches north of the Pembina delta in T. 163 and 164, R. 57, are composed of sand suitable for mixing with clay. Along the banks of the Pembina and Little Pembina rivers many fine exposures of sand, gravel and boulders are found, as in section 36, T. 163, R. 57, and extending northeast for a mile. On the Pembina delta in sections 13, 14, 23, and 24, T. 162, R. 57, are found good gravel deposits, which also occur in section 18, T. 162, R. 56. The Campbell embankment west of Cavalier, in T. 161, R. 55 and 56, is formed of sand suitable for mixing with clay. The Herman, Norcross, Tintah and Campbell beaches in T. 158, 159 and 160, R. 56, show much sand and gravel. These extend southeast of Edinburg, where the Great Northern railroad has opened a gravel pit in the Norcross beach. The "mountain" which extends south from Edinburg through T. 157, 156 and 155, R. 56, is a glacial moraine. The drift composing it contains many boulders, sand, clay and gravel, which is especially well shown on the South Branch of Park river. At Arvilla there is a large gravel pit opened by the Great Northern railway. The morainal deposits in Cavalier county, in the southeast corner of T. 159, R. 64, and in T. 160, R. 61 and 62, contain good gravel suitable for road-making.

The soil of the Red River Valley is typical of the other river valleys of the state, though they are much narrower. The fact that the flood plains of the rivers are relatively narrow and that abundant supplies of gravel occur along the sides of the valleys make well surfaced roads cost much less than similar roads in the wide valley of the Red river. The distance of road material from the place where it is to be used largely determines the cost, and sometimes actually prevents improvement. The valley of the Mouse river along its northward course is very wide. Very little gravel occurs in the valley proper though gravel terraces are found along the river bank, and on the edge of the bench land bordering the valley. The gravel in the latter location varies in size from fine material to large water worn pebbles.

The central part of the state in common with the eastern has no natural rock desirable for road material. In the neighborhood of Denbigh occur sand dunes which supply good material to mix

with the valley clays. It is a matter of common observation that here and there in North Dakota are found stretches of sand-clay roads never known to be bad. This fact has led to numerous experiments with varying results, but all indicate that the essentials to success in sand-clay road building are puddling and saturation. By puddling is meant that the clay is mixed until it is homogeneous. Saturation means that sand is added until each grain is in contact with other grains on all sides. The scarcity of road metals in North Dakota indicates that sand will have to be used in many cases as a substitute for other materials. So many experiments have been carried on by the government and local organizations that no doubt now remains but that sand and clay when properly mixed make a road that will stand the severity of public travel. For this reason, it is desirable to know the location of sand pits and sand dunes. None except sand composed of angular grains is adapted to sand-clay road making. Sand with grains which are rounded, or sand which has been ground up by the action of wheels or water until very fine is unsatisfactory and often worthless. The use of such material should be avoided, as a perfect bond cannot be effected. Care should always be taken to select the sharpest and cleanest sand that can be found. Ferruginous clays are the best and chalky clays are the poorest for road-building purposes. Sedimentary clays are quite difficult to get fully saturated with sharp sand so as to become unyielding and homogeneous.

The numerous sandbars and gravel terraces along the Mouse, James, Missouri, Sheyenne rivers and their tributaries form a widely scattered and abundant supply of these materials for many parts of the state. For many years to come sand and gravel will be the surfacing material for the wagon roads of North Dakota.

The Glacial Drift Plain. Thirty-two counties of the state are more or less covered with glacial drift. The drift extends west from the Red River Valley and exclusive of the river valleys takes in all the remainder of the state except Stark, Bowman, Billings, Adams and Hettinger counties in the southwestern part. The chief characteristic of this area is its imperfect drainage, Kidder county, for example, having no rivers. Throughout this region there are many marshy, swampy places which need to be graded. The surface is a gentle rolling prairie, and the road work to be done will usually consist largely of cutting down the elevations and filling up the depressions.

The soil of the glaciated part of the state is admirably adapted to making a natural road surface. It is a glacial drift composed of sand and clay, and containing some gravel and boulders. This area is abundantly supplied with scattered rock which was brought by the ice-sheet and left scattered over the surface. The cost of good permanent roads per mile in the glaciated region is less than for the same class of roads in the valleys.

The drift contains a varying amount of gravel, often in sufficient quantity for road building. Throughout North Dakota the glacial deposit forms a mantle of such thickness and extent that exposures of the underlying bed-rock are very rare or wholly absent. West of the Missouri river the drift thins out until the underlying rock is exposed in several counties. Where the continental glacier in its retreat remained stationary for a time it built terminal moraines, or hills, knolls, and ridges of drift heaped along the ice border. There are eleven of these moraines which form hilly belts in the eastern half of North Dakota. These are a possible source of road surfacing materials over a large part of the state. In many places there is just the right proportion of clay and sand to make an excellent road. In very few places is the soil as sticky and slippery as the lacustrine silt of the Red River Valley.

While the ice was retreating there was a large amount of water flowing from its outer border. These streams sorted the materials of the drift and left deposits of gravel and sand in many places. This modified or stratified drift is found in many counties of the state, and its gravels are available for roads. Taken as a whole, the roads in the glaciated parts of the state are superior in their unimproved condition to similar roads of the valleys. While in some respects North Dakota is poorly supplied with road making materials, yet no state can boast of a larger proportional number of miles of road which give continuous satisfactory service. And this is due to the glacial drift and its natural adaptation to road surfacing.

Great numbers of boulders occur in the drift covered area, most of them composed of igneous rock. If broken and crushed, these would afford excellent road materials.

Roads in the Unglaciated Area. In that portion of the state which is not covered with drift different conditions prevail. The surface is well drained by the numerous streams, and there are none of the marshes, swamps, and lakes of the drift plain. While

much of the region is a gently rolling plain, where the roads have gradual grades, along the main streams, particularly the Little Missouri, the country is exceedingly rough, and the roads for the most part either follow the streams or the divides. The badlands are confined largely to the Little Missouri, and form a belt from fifteen to twenty miles wide, within which the streams have dissected the surface into a labyrinth of valleys, ravines and gorges.

Throughout this section there is very little gravel for road surfacing. On the other hand, soft sandstone and shale are abundant, though their usefulness as a road building material is doubtful. If the sandstone was used for road purposes, it would rapidly disintegrate into sand, though it may have a function in forming fills. The shale occurs in all gradations from sandy to clayey. What has been said of the sandstone can also be said of the arenaceous shale. Both may endure for a long time in fills when kept from the disintegrating action of climate and wagon wheels. The highway engineer in choosing either of these road metals should have data from the testing laboratory. Morrison, in his Highway Engineering, says that argillaceous shale is unsuited for road building purposes. It weathers into a slippery clay. It is important that these facts should be known, as it may save money to road builders by causing them to discard the sandstone and shale in favor of a more durable road metal.

A road surfacing material is found in the southwestern counties which does not occur in any other section of the state. This is burnt clay, frequently called scoria. In other states of the Union where wood is plentiful, one method of hardening the prepared road surface is by burning wood which is piled upon it.

Here in North Dakota we have an abundance of clay already burned. Lignite coal beds, many hundred square miles in extent, have burned out in places, leaving a vast amount of clay burned to a bright red color. If fully burned the material is entirely changed in character, and when wet it has no tendency to form mud. The heat entirely destroys the plasticity and a light clinker is formed which, though not particularly hard, when pulverized forms a smooth surface and seems to wear well. It is used for sidewalks, crosswalks, and paving in some of the smaller western towns of the state, and is proving highly satisfactory. It is hard, absolutely clean, and does not wash easily. Moreover it is easily handled.

Found in small flakes on the surface of the ground it can be shoveled into a wagon as easily as loose coal. When it is remembered that burned clay occurs in large quantities in several counties, it will be seen that it is one of the important road surfacing materials of the state.

CLIMATE AND ROADS.

There is a very close relation between the climate of a state and the character of its roads. Climate profoundly modifies topography and topography is presumably the most important factor affecting roads. For example, in the eastern part of North Dakota the rainfall is moderate while in the western part of the state it usually occurs in a torrential manner. Now it is easily seen that the surface in the latter section will be washed and gullied more than where the rain falls slowly. Also, where the rain comes gently more of it soaks into the ground, making the soil spongy in the summer and heaving it in the winter. A sandy soil will permit water to pass through, while a clay surface retains water. The natural forces to be withstood by a road metal are: 1. Heavy rains, which tend to wash the road. 2. Winds, which have a tendency to sweep away all the fine material ground up by travel, instead of allowing it to become consolidated again with the mass of the road. 3. Great changes of temperature. 4. Frost. The effect of the first and last of these forces in the different parts of the state is varied. Under any condition a road has to lie open to rain. A heavy rainfall on a clay soil makes the road soft in summer, and frost loosens the bed of the road in winter, adding to the softness each succeeding summer. The rain cannot be kept off the road, but highway construction can keep the water from soaking into the road. The two important effects of rain are washing the surface of the road bed, and soaking the foundation. In the Red River Valley, the washing of the road surface is inconsiderable, but the soaking of the sub-surface is often disastrous. When the base is saturated with water the whole roadbed becomes soft and traffic is stopped. On the other hand, the effect of rain in the unglaciated section is reversed. When the roadbed is not placed upon the natural rock foundation, it has a sandy base which lets the water pass through it. When, however, the rain comes in the usual torrential manner, the road surface is badly washed and gullied.

WINDS

Winds, which tend to sweep away all the fine material ground up by traffic, have little effect on valley roads. Their great influence is noticeable in the glaciated part of the state where the soil is of a sandy nature. This fine material has a cementing influence if allowed to wash into the surface of the road. Good binding power has long been known to road builders to be one of the most important properties possessed by a satisfactory road stone. If the fine material of a road binds well, it protects the foundation of the road from soaking, and withstands better the action of the wind and rain. Cementing power is a very important and valuable property of any road material.

The soil of the river valleys of North Dakota bonds well. This is easily recognized from the appearance of a dry road that was badly cut up by wagon wheels when wet. After baking in the sun the uneven edges are cemented powerfully enough to sustain a heavily loaded wagon. If such a road surface were smoothed before drying it is seen that while dry it would prove an ideal highway. Then, again, if the natural surface can be manipulated to prevent soaking and capillary action, the road building process in river valleys is practically solved.

The soil in the glaciated area does not bind so well as that of the river valleys, but containing a large proportion of gravel, it is on the whole better than that of the valleys. Great changes of temperature are characteristic of the whole state. The rapid freezing and thawing will always be an important disintegrating factor, lessened only when water is kept from the surface and foundation of the road.

SOME RULES OF ROAD BUILDING.

While it is true that each road officer knows best the conditions which prevail in his own community, there are some general rules applicable to all places.

First, what shall be the cross-section profile. From side to center it should rise from one to three inches per foot, depending upon other conditions. An arc of a circle is often used, and is a very good form, but on the whole a curve more convex toward the center than toward the sides is best. If there is no grade the roadbed does not need much crown. The crown should increase as the grade increases. On a level road, the water is cast off at right angles from the center of the road. Now if the grade increase

and the crown of the roadbed does not, the water will run down the road quite a distance before it reaches the side, that is, providing there are no ruts or wagon tracks. If these are present water starting from the center of the road, before reaching the ditch, will flow into the wagon tracks, and thus down the grade, gullyng the road in this manner. Some figures might be used to illustrate the relationship between crown and grade. Suppose a smooth road has a ten per cent grade and a ten per cent crown. Water starting from the center of the roadbed would flow away from it at an angle of forty-five degrees from the center line of the road. In a road of greater grade and less crown the water would never reach the ditch, but would flow down the wagon tracks. It has been determined that the crown should never be less than the grade and preferably a little greater.

While the cross-section is important, it is probably not so important as the gradient. The force necessary to pull a load on level macadam road is one-thirtieth of the load. A gradient of one in thirty doubles the above force. Descending, a load will just move of itself. Now if a load pulls three and one-half times as heavy on sand as on macadam, the force required on a level sand road will be seven-sixtieths of the load. To this add any considerable gradient and it will be seen that the load will have to be cut down to keep it within horse-power.

MACHINERY.

What will be the machinery used to produce the desired cross-section and gradient? In a level country the grader is the ideal machine. It will not only remove the material from the ditch to the roadbed, but will give the surface the desired form. That which seems more important than the machinery to make the first roadbed is the machinery to keep the roadway reshaped and recrowned. Two simple but important home-made implements are worthy of consideration. The first of these is the home-made roller. A number of two-by-fours cut to the desired length of the roller are stood on end in a circular form and fastened together. In the center of this cylinder a gas pipe is placed, protruding at either end. Then the roller is filled with cement. A tongue is attached to the ends of the gaspipe. Any desired weight of roller can be obtained by varying the diameter of the cylinder.

The other implement referred to is the King split log drag used in many states. The Minnesota State Highway Commission has

adopted it, their description of which is found in the Road Red Book. One very important feature of proper road maintenance is that of keeping the ruts out by continual dragging. The split log drag is easily and cheaply constructed and consists of the two halves of a ten or twelve inch log, eight feet long, framed together after the manner of a wooden rack, and drawn with the split faces to the front along each side of, and at an angle of forty-five degrees to the line of the road. This drag should be used while the road is wet as it is then in the best condition for puddling and smoothing. During each dry period the attrition of wheels has ground up some fine material. Mention has already been made of the binding properties of this fine matter. Binding power is probably the most important property to be sought for in any road surface, and its presence is always necessary for the best results. Now, a rain soaks this binding material into the surface of the roadbed. Continued application of the split log drag puddles it, and spreads concentric layers of impervious material over the surface of the road. This puddled surface will not only turn water but capillary action is almost entirely stopped, so that it will not soak up water from a wet foundation. A road treated in this manner has as good a rain proof roof as the shingled dwelling house, provided the soil has a natural binder in it. Now it may be safely assumed that any soil which dries into hard impervious lumps has a natural binder. These seem to be the two simple, popular and universally used road machines.

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